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In order to evaluate our methods and approaches of estimating the operating characteristics of discrete item responses, it is necessary to try other comparable methods on similar sets of data. LOGIST 5 was taken up for this reason, and was tried upon the hypothetical test items, which follow the normal ogive model and were used frequently in testing our own methods and approaches. The two sets of simulated data used are based upon 500 and 2,000 hypothetical examinees respectively. It was found out that LOGIST 5 provides good parameter estimates under certain conditions, in preference to certain other conditions. (Author)

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RESULTS OF ITEM PARAMETER ESTIMATION USING LOGIST 5 ON SIMULATED DATA

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RESULTS OF ITEM PARAMETER ESTIMATION USING LOGIST 5 ON SIMULATION DATA

ABSTRACT

In order to evaluate our methods and approaches of estimating the operating characteristics of discrete item responses, it is necessary to try other comparable methods on similar sets of data. LOGIST 5 was taken up for this reason, and was tried upon the hypothetical test items, which follow the normal ogive model and were used frequently in testing our own methods and approaches. Two sets of simulated data we used are based upon 500 and 2,000 hypothetical examinees, respectively. It was found out that LOGIST 5 provides us with good parameter estimates under certain conditions, in preference to certain other conditions.

The research was conducted at the principal investigator's laboratory, 405 Austin Peay Hall, Department of Psychology, University of Tennessee, Knoxville, Tennessee. Those who worked for her as assistants include Paul S. Changas, Mehrdad A. Saravi, Deborah Wichlan and Cindy Wheatley-Lovoy.

I. Introduction

Three-parameter logistic model (Birnbaum, 1968) has widely been used for the multiple-choice test item in mental measurement among psychometricians and other researchers. Let θ be the latent trait, or ability, and $P_g(\theta)$ be the item characteristic function of the multiple-choice test item g, or the conditional probability with which the examinee answers item g correctly, given ability θ. In the three-parameter logistic model, this item characteristic function is given by

$$P_g(\theta) = c_g + (1-c_g)\,\Psi_g(\theta) \quad , \tag{1.1}$$

where $\Psi_g(\theta)$ is the item characteristic function in the (two-parameter) logistic model, for which we can write

$$\Psi_g(\theta) = [1 + \exp\{-Da_g(\theta-b_g)\}]^{-1} \quad , \tag{1.2}$$

with a_g (> 0) and b_g as the item discrimination and difficulty parameters, and D as the scaling factor which is usually set equal to 1.7, respectively. The third parameter, c_g, in (1.1) is the guessing parameter, which is originally defined as unity divided by the number of alternative answers presented with the multiple-choice test item g.

The model was originated from the assumption that the examinee either knows the answer to the question, or guesses randomly. Thus

$P_g(\theta)$, or the operating characteristic of the binary item score $u_g = 1$, given θ , is greater than $\Psi_g(\theta)$, which represents the conditional probability for the "knowledge." The discrepancy between the two functions is also a function of θ , i.e., $[1 - \Psi_g(\theta)]$ divided by the number of alternatives.

Lord started calling this third parameter, c_g , pseudo-guessing parameter, after he had discovered that for many multiple-choice test items, when the three-parameter logistic model was adopted, the estimated c_g substantially differs from unity divided by the number of alternatives (Lord, 1968). It appears that this fact itself is enough evidence to invalidate the three-parameter logistic model with respect to those specific test items. The model has been continued to be used by many researchers, however, for almost any types of multiple-choice test items. They claim that, although they are aware of the fact that the philosophy behind the model is invalid, there should not be any harm as long as the curve is used as an approximation to the true item characteristic function.

The author does not agree with this conviction. Nor does she consider it harmless to use this third parameter, c_g , when its original meaning has been rejected. The issue must be pursued theoretically and empirically <u>before</u> this model is used as an "approximation" to the true item characteristic function.

It has been pointed out (Samejima, 1977) that, unlike the normal ogive and the logistic models, three-parameter logistic model does not satisfy the unique maximum condition (Samejima, 1969, 1972),

which indicates that for some response patterns the likelihood function $L_V(\theta)$, i.e., the operating characteristic of the response pattern, V, may not have a unique maximum. This fact implies that the third parameter, c_g, can be a real nuisance.

In the present paper, the issue is pursued from another angle. Suppose that our multiple-choice test items actually follow the normal ogive model, whose item characteristic functions are given by

$$(1.3) \qquad \Phi_g(\theta) = (2\pi)^{-1/2} \int_{-\infty}^{a_g(\theta - b_g)} \exp(-t^2/2)\, dt \ ,$$

where a_g (> 0) and b_g are the item discrimination and the item difficulty parameters, respectively. It is well known (Birnbaum, 1968) that the logistic model, whose item characteristic function is given by (1.2), is a good approximation to the normal ogive model when the same set of item parameters are used and the scaling factor D is set equal to 1.7. Our question in the present study is: if we assume the three-parameter logistic model for these test items, instead of the normal ogive or logistic model, and estimate the three item parameters simultaneously using an appropriate method, shall we obtain the estimate of c_g which is close enough to the true value, zero, and the estimates of a_g and b_g which are close enough to their true values? Or will this additional parameter c_g contaminate the result so that we will be provided with a substantially different set of estimated item parameters?

Data adopted in the present research are simulated data, which will be described in detail in Section 2. They are produced by the Monte Carlo method using hypothetical test items following the normal ogive model with specified sets of parameters. In estimating the three item parameters assuming the three-parameter logistic model, Logist 5 was used for those data based upon the hypothetical test items. Logist 5 is a computer program developed by Lord and others (Wingersky, Barton and Lord, 1982) for the purpose of estimating the item discrimination parameter a_g, the item difficulty parameter b_g and the guessing parameter c_g of each test item g $(=1,2,\ldots,n)$ following the three-parameter logistic model, as well as the individual ability parameter θ_s of each examinee s $(=1,2,\ldots,N)$. The method is based upon the maximum likelihood estimation, with the likelihood function,

$$(1.4) \qquad L(U|\Theta,A,B,C) = \prod_{s=1}^{N} \prod_{g=1}^{n} P_g(\theta_s)^{u_{gs}} \{1-P_g(\theta_s)\}^{1-u_{gs}},$$

where u_{gs} is a binary item score of the examinee s for item g, U is an (nxN) matrix of the binary item scores u_{gs}, Θ is the vector of order N of the individual parameter θ_s, A, B and C are the vectors of order n of the item parameters a_g, b_g and c_g, respectively. Those $(3n+N)$ parameters are estimated iteratively through the four sets of likelihood equations, with devices to make their convergence speedy.

The resultant estimated item parameters and individual

parameters will be presented in later sections, and the estimated item characteristic functions will be compared with the true item characteristic functions, which follow the normal ogive model. Some theoretical observations will be made, which will explain certain features of our results.

II. Simulated Data

There are basically two sets of hypothetical test items, all of which follow the normal ogive model. The first set consists of ten binary test items, which were used as "unknown" test items in the author's previous research on the nonparametric approach to the operating characteristic estimation (Samejima, Final Report, 1981). The item discrimination and difficulty parameters, a_g and b_g, in (1.3) for each of these ten items are shown in Table 2-1. The second test consists of thirty-five binary test items, and their discrimination and difficulty parameters are shown in the two middle columns of Table 2-2. These values were also used as the discrimination parameters and the first set of difficulty parameters of the "Old Test" items having three item score categories each in the previous research. Thus we have forty-five binary test items in total. For brevity, hereafter, we shall call these two sets of hypothetical binary test items Ten Item Test and Thirty-Five Item Test, respectively.

Five hundred examinees whose ability distributes uniformly within the interval of θ, $(-2.5, 2.5)$, were hypothesized, as we did

TABLE 2-1

Item Discrimination Parameter a_g and Item Difficulty Parameter b_g of Each of the Ten "Unknown" Test Items, Following the Normal Ogive Model.

Item g	a_g	b_g
1	1.5	-2.5
2	1.0	-2.0
3	2.5	-1.5
4	1.0	-1.0
5	1.5	-0.5
6	1.0	0.0
7	2.0	0.5
8	1.0	1.0
9	2.0	1.5
10	1.0	2.0

TABLE 2-2

Item Discrimination Parameter a_g And Two Item Difficulty Parameters b_{x_g} (x_g = 1,2) of Each of the Thirty-Five Old Test Items, Following the Normal Ogive Model.

Item g	a_g	b_1	b_2
1	1.8	-4.75	-3.75
2	1.9	-4.50	-3.50
3	2.0	-4.25	-3.25
4	1.5	-4.00	-3.00
5	1.6	-3.75	-2.75
6	1.4	-3.50	-2.50
7	1.9	-3.00	-2.00
8	1.8	-3.00	-2.00
9	1.6	-2.75	-1.75
10	2.0	-2.50	-1.50
11	1.5	-2.25	-1.25
12	1.7	-2.00	-1.00
13	1.5	-1.75	-0.75
14	1.4	-1.50	-0.50
15	2.0	-1.25	-0.25
16	1.6	-1.00	0.00
17	1.8	-0.75	0.25
18	1.7	-0.50	0.50
19	1.9	-0.25	0.75
20	1.7	0.00	1.00
21	1.5	0.25	1.25
22	1.8	0.50	1.50
23	1.4	0.75	1.75
24	1.9	1.00	2.00
25	2.0	1.25	2.25
26	1.6	1.50	2.50
27	1.7	1.75	2.75
28	1.4	2.00	3.00
29	1.9	2.25	3.25
30	1.6	2.50	3.50
31	1.5	2.75	3.75
32	1.7	3.00	4.00
33	1.8	3.25	4.25
34	2.0	3.50	4.50
35	1.4	3.75	4.75

in the previous research. Actually, there are one hundred discrete points of θ ranging from -2.475 to 2.475 with the equal step of 0.050 , and five hypothetical subjects are placed at each ability level. The response pattern for each of these five hundred hypothetical subjects was already produced in the previous research with respect to the ten "unknown" test items as well as to the thirty-five "Old Test" items of three item score categories each. In the present research, the binary item scores for the ten "unknown" test items were used as they are, but the thirty-five graded item scores for the "Old Test" items were reduced to the binary scores by using the first set of difficulty parameters as the sole boundaries. In order to investigate the effect of the number of test items on the resultant estimated parameters obtained by Logist 5, we used: 1) the first ten items, 2) the second thirty-five items, and 3) the forty-five items combining these two sets of items, separately.

As an additional observation, we wished to increase the number of items in the total set of binary items for which Logist 5 was to be applied. Thus another set of thirty-five binary test items was added more or less artificially, by using the same thirty-five discrimination parameters and the second set of difficulty parameters of the "Old Test," which is given in the last column of Table 2-2. The part of the response pattern of these thirty-five binary test items was created for each examinee by reducing his original response pattern of the "Old Test" items of graded scores, as we did for the previous subset of thirty-five binary item scores. In this way, each

examinee has a response pattern of eighty binary item scores in total. The second and the third subsets of thirty-five binary test item scores in this largest response pattern were created from the same response pattern of the "Old Test" items of graded scores, however. These additional thirty-five items were solely used for the purpose of increasing the number of binary test items in using Logist 5 upon which the item parameters of the above forty-five test items were estimated. Thus in addition to the three cases described earlier, we have: 4) the eighty items adding those "artificial" thirty-five items to the forty-five items. Hereafter, we shall call these four different situations Cases 1, 2, 3, and 4, respectively.

For the purpose of investigating the effect of the number of examinees on the resultant estimated parameters obtained by Logist 5, an additional group of one thousand five hundred examinees were further hypothesized, to provide us with a larger group of two thousand examinees, whose ability follows the same uniform distribution. Thus in this larger group twenty examinees are placed at each of the one hundred equally spaced discrete ability levels, which were described earlier. The response pattern of the forty-five binary test item scores and the additional thirty-five "artificial" binary test item scores was produced in exactly the same way for each of these additional one thousand five hundred hypothetical examinees, as it was produced for each of the five hundred subjects. For brevity, hereafter, we shall call these two situations 500 Subject Case and 2,000 Subject Case, respectively, depending upon the number

of hypothetical examinees included in the sample.

Figure 2-1 presents the square root of the test information function, $I(\theta)$, of each of the four sets of test items, i.e., those in Cases 1, 2, 3 and 4. This function is given as the square root of $I(\theta)$, for which we can write

$$(2.1) \quad I(\theta) = \sum_{g=1}^{n} I_g(\theta) \quad ,$$

where $I_g(\theta)$ is the item information function in the normal ogive model, for which we have

$$(2.2) \quad I_g(\theta) = [\frac{\partial}{\partial\theta} \Phi(\theta)]^2 \; [\Phi_g(\theta) \{1-\Phi_g(\theta)\}]^{-1} \quad ,$$

where $\Phi_g(\theta)$ is the item characteristic function in the normal ogive model given by (1.3). We can see in Figure 2-1 that the amount of information provided by the Ten Item Test is substantially smaller than the others, especially outside of the interval of θ, $(-2.0, 1.5)$. This fact is naturally expected to affect the accuracy of estimation of the individual parameters of the examinees as well as that of the item parameters when Ten Item Test is used.

III. Scale Adjustment

In the results of Logist 5, the origin and the unit of the ability scale is adjusted to the mean and the standard deviation of the sample distribution of the estimated individual ability parameters

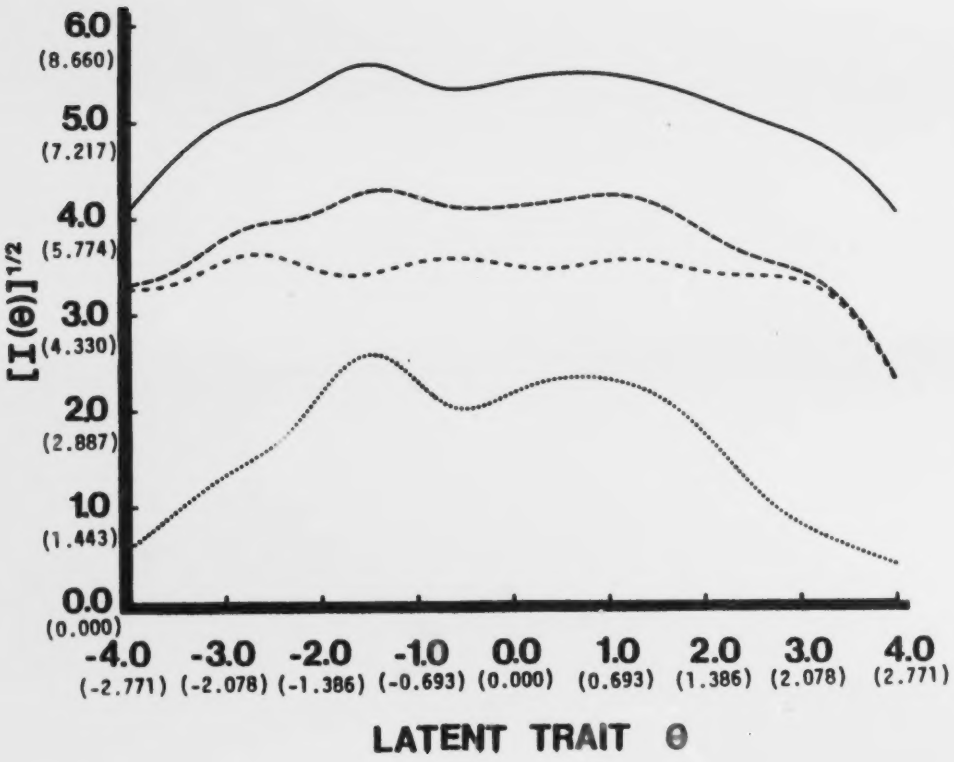

FIGURE 2-1

Square Roots of Test Information Function of the Ten Item Test (Dotted Line), of the Thirty-Five Item Test (Short Dashed Line), of the Forty-Five Item Test (Long Dashed Line) and of the Eighty Item Test (Solid Line).

of the examinees, which did not exceed 3.0 in absolute values after the last iteration. This implies that, if we use different sets of binary test items, because of the error of estimation the resultant ability scales will be slightly different from each other, even though the group of hypothetical examinees is fixed. It further implies that, if we use different examinee groups for the same set of binary items in using Logist 5, the resultant ability scales will also be affected. As long as we know the true item parameters, as we do in the present research, it is possible to pursue the bivariate distribution of the maximum likelihood estimate, $\hat{\theta}_s$, and θ_s itself, and we can adjust each scale accordingly. There is no simple, straightforward functional relationship between θ_s and $\hat{\theta}_s$, however. In Logist 5, moreover, $\hat{\theta}_s$ is treated as if it were θ_s itself in estimating the item parameters in the three parameter logistic model, and there is no simple way to adjust this bias. For this reason, it will be more appropriate to compare the result of estimation directly with the theoretical item characteristic function without making any scale adjustment, knowing that any discrepancies may be due to those scale differences.

The theoretical item and individual parameters were transformed in order to make them comparable to the estimated parameters obtained by Logist 5. In so doing, a linear transformation of the ability scale was performed by using the mean and the standard deviation of the uniform distribution of θ as the origin and the unit of the new scale. We can write for the expectation and the variance of any

uniform distribution

$$(3.1) \qquad E(\theta) = \int_{\alpha}^{\beta} (\beta-\alpha)^{-1} \theta \, d\theta = (\alpha+\beta)/2$$

and

$$(3.2) \qquad Var.(\theta) = \int_{\alpha}^{\beta} (\beta-\alpha)^{-1} \theta^2 \, d\theta - [E(\theta)]^2 = (\beta-\alpha)^2/12 \ ,$$

where α and β are the lower and upper endpoints of the interval of θ for which the distribution is uniform. In order to adjust the origin and the unit of the scale of θ to the mean and the standard deviation of the distribution, therefore, we must shift the origin of θ to the midpoint of the interval, (α,β), and multiply the unit of θ by $(\beta-\alpha)/(2\sqrt{3})$. Since both of our two examinee groups have the same uniform distribution with $\alpha = -2.5$ and $\beta = 2.5$, respectively, the midpoint of the interval equals zero, and the standard deviation of the distribution is $5/(2\sqrt{3})$, which is approximately equal to 1.443375673. Thus the resultant new scale of θ should have the same origin as before, and its unit should be approximately 1.4434 times larger than the original unit.

This transformation of the scale of θ accompanies that of the true individual ability parameters of our hypothetical examinees. On the new scale of θ they are placed at one hundred equally spaced ability levels starting from approximately -1.714730299 and ending with 1.714730299, with the equal step of approximately 0.034641016.

The theoretical uniform distribution on the new scale of θ has the interval, $(-\sqrt{3}, \sqrt{3})$, which is approximately equal to (-1.732050808, 1.732050808), for which the uniform density is $(2\sqrt{3})^{-1}$, or approximately 0.288675134. The maximum likelihood estimate, θ_g, of the individual parameter obtained upon the true item characteristic functions was also transformed, accordingly, and so were the item discrimination parameter a_g and the item difficulty parameter b_g for each item g, i.e., the original value of the former was multiplied by $5/(2\sqrt{3})$ and that of the latter was divided by the same value. These results are shown as Tables 3-1 and 3-2 for the ten items and the two sets of thirty-five items, respectively. The transformation of θ also affects the values of the square root of the test information function of each hypothetical test. Since it is a linear transformation, however, the shape of each curve in Figure 2-1 is still preserved. The new scale values of θ and the resultant values of the square root of the test information function are indicated in parentheses in Figure 2-1, which was presented in the preceding section.

IV. Estimated Item Parameters

Table 4-1 presents the estimated item parameters in Case 1 obtained by Logist 5, in both 500 and 2,000 Subject Cases, together with the corresponding theoretical item parameters following the normal ogive model, for each item of the Ten Item Test. In using Logist 5, the upper limit of the estimated a_g was set equal to

TABLE 3-1

Transformed Item Discrimination Parameter a_g and Item Difficulty Parameter b_g of Each Item of the Ten Item Test.

Item g	a_g	b_g
1	2.16506	-1.73205
2	1.44338	-1.38564
3	3.60844	-1.03923
4	1.44338	-0.69282
5	2.16506	-0.34641
6	1.44338	0.00000
7	2.88675	0.34641
8	1.44338	0.69282
9	2.88675	1.03923
10	1.44338	1.38564

TABLE 3-2

Transformed Common Item Discrimination Parameter a_g And Item Difficulty Parameter b_g of Each Item of the Thirty-Five Item Test (Third Column) And of the Additional Set of Thirty-Five Items (Fourth Column).

Item g	a_g	b_1	b_2
1	2.59808	-3.29090	-2.59808
2	2.74241	-3.11769	-2.42487
3	2.88675	-2.94449	-2.25167
4	2.16506	-2.77128	-2.07846
5	2.30940	-2.59808	-1.90526
6	2.02073	-2.42487	-1.73205
7	2.74241	-2.07846	-1.38564
8	2.59808	-2.07846	-1.38564
9	2.30940	-1.90526	-1.21244
10	2.88675	-1.73205	-1.03923
11	2.16506	-1.55885	-0.86603
12	2.45374	-1.38564	-0.69282
13	2.16506	-1.21244	-0.51962
14	2.02073	-1.03923	-0.34641
15	2.88675	-0.86603	-0.17321
16	2.30940	-0.69282	0.00000
17	2.59808	-0.51962	0.17321
18	2.45374	-0.34641	0.34641
19	2.74241	-0.17321	0.51962
20	2.45374	0.00000	0.69282
21	2.16506	0.17321	0.86603
22	2.59808	0.34641	1.03923
23	2.02073	0.51962	1.21244
24	2.74241	0.69282	1.38564
25	2.88675	0.86603	1.55885
26	2.30940	1.03923	1.73205
27	2.45374	1.21244	1.90526
28	2.02073	1.38564	2.07846
29	2.74241	1.55885	2.25167
30	2.30940	1.73205	2.42487
31	2.16506	1.90526	2.59808
32	2.45374	2.07846	2.77128
33	2.59808	2.25167	2.94449
34	2.88675	2.42487	3.11769
35	2.02073	2.59808	3.29090

TABLE 4-1

Theoretical and Estimated Item Parameters in the 500 and 2,000 Subject Cases for Each Item of the Ten Item Test. Three-Parameter Logistic Model Is Assumed. Case 1.

Item	Discrimination Parameter				Difficulty Parameter				Guessing Parameter	
	Theoretical		Estimated		Theoretical		Estimated		Estimated	
	Org.	Adj.	500 S.C.	2,000 S.C.	Org.	Adj.	500 S.C.	2,000 S.C.	500 S.C.	2,000 S.C.
1	1.50000	2.16506	4.00000	0.95615	-2.50000	-1.73205	-7.00850	-4.53097	0.11111	0.00000
2	1.00000	1.44338	1.12847	1.89857	-2.00000	-1.38564	-2.27705	-1.25111	0.11111	0.23137
3	2.50000	3.60844	4.00000	7.00000	-1.50000	-1.03923	-1.49140	-1.02797	0.01285	0.01897
4	1.00000	1.44338	1.49368	2.16571	-1.00000	-0.69282	-0.76647	-0.34862	0.12154	0.15474
5	1.50000	2.16506	4.00000	5.73384	-0.50000	-0.34641	-0.39155	-0.07764	0.01397	0.04219
6	1.00000	1.44338	1.81350	2.45766	0.00000	0.00000	-0.00846	0.25474	0.04756	0.06358
7	2.00000	2.88675	3.08340	6.30172	0.50000	0.34641	0.32296	0.49745	0.00000	0.00499
8	1.00000	1.44338	1.47734	2.11129	1.00000	0.69282	0.72304	0.81349	0.00000	0.00645
9	2.00000	2.88675	4.00000	5.73230	1.50000	1.03923	1.10169	1.04610	0.00000	0.00000
10	1.00000	1.44338	0.65759	0.98121	2.00000	1.38564	2.60342	2.08713	0.00000	0.00000

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4.00 in the 500 Subject Case, while the lower and upper limits of the estimate of the individual parameter θ_s were set equal to -7.00 and 4.00 , respectively. We can see in Table 4-1 that as many as four out of the ten estimated item discrimination parameters assume this maximum value, 4.00 , the result which was not expected. For this reason, in all the other situations, this upper limit was changed to 7.00 , while the lower and upper limits of the estimated individual parameter remained unchanged. The results of the 2,000 Subject Case in Table 4-1 are based upon this new set of maximum and minimum values. We can see in Table 4-1 that, even with the larger upper limit set for the item discrimination parameter, one of the estimated item discrimination parameters, i.e., that of item 3, assumes this maximum value. Since this item has the largest theoretical discrimination parameter, 3.60844 , this result is understandable in a sense, and yet we must say that the estimated parameter is very much "inflated." This is a general tendency over all the ten items, especially in the 2,000 Subject Case. On the other hand, the estimated difficulty parameters do not show such a conspicuous tendency. A close examination of the results of the 2,000 Subject Case reveals, however, that with the exception of item 1, whose true difficulty parameter equals the lower end of the interval of θ for which the ability distribution is uniform, all the other item difficulty parameters are overestimated, although the same tendency does not appear in the results of the 500 Subject Case. The estimated guessing parameters turned out to be substantially large for

the items of lower difficulty parameters and of smaller discrimination parameters.

For the sake of comparison, Logist 5 was used for the same two sets of data by setting c_g equal to zero, i.e., by assuming the logistic model instead of the three-parameter logistic model. Table 4-2 presents the resultant estimated item discrimination and difficulty parameters for both 500 and 2,000 Subject Cases, together with their theoretical parameters, for each item of the Ten Item Test. We can see in this table that the estimated discrimination parameters still tend to be "inflated," but not to the extent that they do in the previous results which were obtained without the constraint for c_g. The estimated difficulty parameters are close to the true parameters, except for item 10 in both 500 and 2,000 Subject Cases. Those estimated difficulty parameters scatter more widely, however, compared with the true difficulty parameter values.

The tendencies observed in the results of Case 1 may be, to a certain extent, due to the fact that only ten test items were used for Logist 5. We can expect that the bias caused by its scaling has a substantial effect on the resultant estimated item parameters. In fact, when the three-parameter logistic model was assumed, in the 500 Subject Case as many as one hundred hypothetical examinees were excluded in the process of rescaling, for their latest estimated individual parameters exceeded 3.00 in absolute values. Out of these one hundred hypothetical examinees, eight obtained negative infinity as their individual parameter estimates, which was caused by

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TABLE 4-2

Theoretical and Estimated Item Parameters in the 500 and 2,000 Subject Cases for Each Item of the Ten Item Test. Logistic Model Is Assumed. Case 1.

Item	Discrimination Parameter				Difficulty Parameter			
	Theoretical		Estimated		Theoretical		Estimated	
	Org.	Adj.	500 S.C.	2,000 S.C.	Org.	Adj.	500 S.C.	2,000 S.C.
1	1.50000	2.16506	7.00000	4.46012	-2.50000	-1.73205	-1.79784	-1.82777
2	1.00000	1.44338	1.66645	1.48512	-2.00000	-1.38564	-1.40424	-1.41994
3	2.50000	3.60844	4.83938	4.77435	-1.50000	-1.03923	-1.00147	-0.98488
4	1.00000	1.44338	1.38928	1.55463	-1.00000	-0.69282	-0.64011	-0.63939
5	1.50000	2.16506	3.61872	3.26944	-0.50000	-0.34641	-0.18574	-0.25476
6	1.00000	1.44338	1.53595	1.60692	0.00000	0.00000	0.11857	0.10502
7	2.00000	2.88675	3.38480	4.45453	0.50000	0.34641	0.52054	0.51174
8	1.00000	1.44338	1.70183	1.66029	1.00000	0.69282	0.86021	0.88896
9	2.00000	2.88675	7.00000	6.08234	1.50000	1.03923	1.18334	1.18419
10	1.00000	1.44338	1.00086	1.12968	2.00000	1.38564	2.09119	2.01825

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their "all zero" response patterns, and thirty-nine obtained positive infinity caused by their "all unity" response patterns. The corresponding total number of excluded subjects in the 2,000 Subject Case is two hundred thirty-eight, i.e., still as large as 11.9 percent of the total number of examinees. Out of these subjects, thirty-eight obtained negative infinity as the estimates of their individual parameters, which was caused by their "all zero" response patterns, and one hundred forty-seven obtained positive infinity caused by their "all unity" response patterns. The corresponding numbers of hypothetical examinees excluded in the rescaling process when the (two-parameter) logistic model was assumed are much smaller but still substantial, i.e., forty-seven in the 500 Subject Case and one hundred eighty-five in the 2,000 Subject Case, including those who obtained negative or positive infinities as their individual parameter estimates.

Table 4-3 presents the results of Case 2 obtained for the items of the Thirty-Five Item Test assuming the three-parameter logistic model. For convenience, these thirty-five items are numbered 11 through 45, in order to avoid the confusion caused by using the same item numbers as those of the Ten Item Test. In this table, the estimated item parameters of items 11, 12, 13, 15, 44 and 45 in the 500 Subject Case and those of items 11, 12, 13 and 44 in the 2,000 Subject Case are missing, however, since in each situation either all the hypothetical examinees uniformly obtained zero, or all uniformly obtained unity, as their item scores, and the estimation turned out

TABLE 4-3

Theoretical and Estimated Item Parameters in the 500 and 2,000 Subject Cases for Each Item of the Thirty-Five Item Test. Three-Parameter Logistic Model Is Assumed. Case 2.

Item	Discrimination Parameter				Difficulty Parameter				Guessing Parameter	
	Theoretical		Estimated		Theoretical		Estimated		Estimated	
	Org.	Adj.	500 S.C.	2,000 S.C.	Org.	Adj.	500 S.C.	2,000 S.C.	500 S.C.	2,000 S.C.
11	1.80000	2.59808	---	---	-4.75000	-3.29090	---	---	---	---
12	1.90000	2.74241	---	---	-4.50000	-3.11769	---	---	---	---
13	2.00000	2.88675	---	---	-4.25000	-2.94449	---	---	---	---
14	1.50000	2.16506	7.00000	2.10115	-4.00000	-2.77128	-2.31556	-3.02161	0.08667	0.02122
15	1.60000	2.30940	---	4.95191	-3.75000	-2.59808	---	-2.41505	---	0.02122
16	1.40000	2.02073	7.00000	2.01814	-3.50000	-2.42487	-2.31184	-2.66637	0.08667	0.02122
17	1.90000	2.74241	2.34600	6.25083	-3.00000	-2.07846	-2.49184	-1.97065	0.08667	0.00000
18	1.80000	2.59808	1.66937	2.45684	-3.00000	-2.07846	-2.53506	-2.23919	0.08667	0.02122
19	1.60000	2.30940	5.95996	2.62153	-2.75000	-1.90526	-1.63507	-1.90260	0.33907	0.02122
20	2.00000	2.88675	4.54064	3.93175	-2.50000	-1.73205	-1.75362	-1.66113	0.00000	0.16847
21	1.50000	2.16506	3.60897	3.57269	-2.25000	-1.55885	-1.52887	-1.47593	0.00000	0.00000
22	1.70000	2.45374	3.72440	5.79677	-2.00000	-1.38564	-1.26918	-1.20411	0.19618	0.17118
23	1.50000	2.16506	5.93530	4.14441	-1.75000	-1.21244	-0.86540	-1.04556	0.31164	0.12398
24	1.40000	2.02073	2.15613	2.50797	-1.50000	-1.03923	-0.91905	-0.92924	0.05498	0.08893
25	2.00000	2.88675	4.30412	3.82653	-1.25000	-0.86603	-0.82709	-0.84287	0.00000	0.01227
26	1.60000	2.30940	3.08081	3.00092	-1.00000	-0.69282	-0.61492	-0.62173	0.00000	0.03369
27	1.80000	2.59808	3.41671	3.29292	-0.75000	-0.51962	-0.42482	-0.50742	0.01715	0.00712
28	1.70000	2.45374	3.73975	3.15448	-0.50000	-0.34641	-0.29610	-0.32412	0.00000	0.00000
29	1.90000	2.74241	3.55043	3.43681	-0.25000	-0.17321	-0.16918	-0.15937	0.00000	0.00000
30	1.70000	2.45374	3.26689	2.97724	0.00000	0.00000	0.06045	0.03331	0.00000	0.00000
31	1.50000	2.16506	2.51771	2.68637	0.25000	0.17321	0.24396	0.17012	0.00000	0.00132
32	1.80000	2.59808	3.36240	3.58997	0.50000	0.34641	0.38959	0.35692	0.00000	0.00000
33	1.40000	2.02073	2.49348	2.33960	0.75000	0.51962	0.49717	0.47978	0.00000	0.00000
34	1.90000	2.74241	3.92561	3.63878	1.00000	0.69282	0.64148	0.65455	0.00000	0.00000
35	2.00000	2.88675	4.36628	3.48851	1.25000	0.86603	0.78414	0.85172	0.00000	0.00000
36	1.60000	2.30940	2.61472	2.72612	1.50000	1.03923	1.01803	1.02596	0.00000	0.00000
37	1.70000	2.45374	2.54991	2.90554	1.75000	1.21244	1.21299	1.22349	0.00000	0.00000
38	1.40000	2.02073	1.97089	2.25224	2.00000	1.38564	1.38765	1.34179	0.00000	0.00000
39	1.90000	2.74241	6.12277	3.14405	2.25000	1.55885	1.47525	1.52861	0.07920	0.00000
40	1.60000	2.30940	4.30567	3.39256	2.50000	1.73205	1.51061	1.62665	0.00000	0.00000
41	1.50000	2.16506	2.50260	2.18581	2.75000	1.90526	2.09183	1.97325	0.00000	0.00000
42	1.70000	2.45374	7.00000	6.00998	3.00000	2.07846	1.82767	1.88083	0.00000	0.00000
43	1.80000	2.59808	3.18005	1.91086	3.25000	2.25167	2.10989	2.68272	0.00000	0.00000
44	2.00000	2.88675	---	---	3.50000	2.42487	---	---	---	---
45	1.40000	2.02073	---	7.00000	3.75000	2.59808	---	2.19254	---	0.00198

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to be impossible. The corresponding results obtained by assuming the logistic model are shown as Table 4-4. In both cases, no hypothetical examinees were excluded in the process of rescaling θ, either in the 500 Subject Case or in the 2,000 Subject Case.

It is observed in Table 4-3 that there exists a distinct tendency that the estimated discrimination parameters are "inflated" again for these items of the Thirty-Five Item Test when the three-parameter logistic model was assumed. This tendency is also observed in the results of Table 4-4 obtained by assuming the logistic model both in 500 Subject Case and in 2,000 Subject Case. Comparison of the estimated discrimination parameters across the two tables in each of the 500 and 2,000 Subject Cases reveals that those in Table 4-3 are more inflated than those in Table 4-4, especially for items whose true difficulty parameters are closer to the midpoint of the interval of θ, $(-\sqrt{3}, \sqrt{3})$, for which the ability distribution is uniform. Most of the estimated difficulty parameters are fairly close to the true difficulty parameters, in both sets of results shown in Tables 4-3 and 4-4. A close examination of the results of Table 4-3 reveals, however, that, when the estimated guessing parameter is substantially large, the difficulty parameter tends to be overestimated. As was observed in the results of Case 1, the estimated guessing parameter tends to be substantially large for items whose theoretical difficulty parameters are low. The relationship between the estimated guessing parameter and the theoretical discrimination parameter is not so obvious, however. This may partly be due to the fact that the theoretical item discrimination parameters are closer to one another

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TABLE 4-4

Theoretical and Estimated Item Parameters in the 500 and 2,000 Subject Case for Each Item of the Thirty-Five Item Test. Logistic Model Is Assumed. Case 2.

Item	Discrimination Parameter				Difficulty Parameter			
	Theoretical		Estimated		Theoretical		Estimated	
	Org.	Adj.	500 S.C.	2,000 S.C.	Org.	Adj.	500 S.C.	2,000 S.C.
11	1.80000	2.59808	---	---	-4.75000	-3.29090	---	---
12	1.90000	2.74241	---	---	-4.50000	-3.11769	---	---
13	2.00000	2.88675	---	---	-4.25000	-2.94449	---	---
14	1.50000	2.16506	7.00000	2.66184	-4.00000	-2.77128	-2.24211	-2.72393
15	1.60000	2.30940	---	1.80462	-3.75000	-2.59808	---	-3.48102
16	1.40000	2.02073	5.85000	2.18952	-3.50000	-2.42487	-2.27498	-2.57504
17	1.90000	2.74241	2.65490	4.80292	-3.00000	-2.07846	-2.38002	-1.98730
18	1.80000	2.59808	1.86159	2.27740	-3.00000	-2.07846	-2.43453	-2.28213
19	1.60000	2.30940	3.04990	2.35694	-2.75000	-1.90526	-1.84166	-1.94374
20	2.00000	2.88675	5.26700	3.67092	-2.50000	-1.73205	-1.69718	-1.71751
21	1.50000	2.16506	3.68387	3.53050	-2.25000	-1.55885	-1.51712	-1.48068
22	1.70000	2.45374	2.78792	3.44789	-2.00000	-1.38564	-1.41474	-1.32688
23	1.50000	2.16506	2.29748	3.17041	-1.75000	-1.21244	-1.21515	-1.15032
24	1.40000	2.02073	2.06001	2.20858	-1.50000	-1.03923	-0.98995	-1.02123
25	2.00000	2.88675	4.28130	3.59910	-1.25000	-0.86603	-0.85496	-0.86681
26	1.60000	2.30940	3.00410	2.66034	-1.00000	-0.69282	-0.63407	-0.66631
27	1.80000	2.59808	2.96481	3.16909	-0.75000	-0.51962	-0.45806	-0.52025
28	1.70000	2.45374	3.67673	3.11533	-0.50000	-0.34641	-0.30288	-0.32330
29	1.90000	2.74241	3.46570	3.44479	-0.25000	-0.17321	-0.17130	-0.15421
30	1.70000	2.45374	3.24069	2.95857	0.00000	0.00000	0.06386	0.04162
31	1.50000	2.16506	2.48202	2.63270	0.25000	0.17321	0.24964	0.17709
32	1.80000	2.59808	3.28184	3.56525	0.50000	0.34641	0.39818	0.36913
33	1.40000	2.02073	2.44574	2.33705	0.75000	0.51962	0.50649	0.49057
34	1.90000	2.74241	3.75665	3.62024	1.00000	0.69282	0.65520	0.66711
35	2.00000	2.88675	4.35412	3.52539	1.25000	0.86603	0.79956	0.86196
36	1.60000	2.30940	2.74792	2.81144	1.50000	1.03923	1.02172	1.03020
37	1.70000	2.45374	2.63339	3.03734	1.75000	1.21244	1.21153	1.22028
38	1.40000	2.02073	2.03766	2.36148	2.00000	1.38564	1.38059	1.33170
39	1.90000	2.74241	3.39088	3.39749	2.25000	1.55885	1.45505	1.50674
40	1.60000	2.30940	4.77467	3.54667	2.50000	1.73205	1.49452	1.60441
41	1.50000	2.16506	2.58117	2.27431	2.75000	1.90526	2.07618	1.93828
42	1.70000	2.45374	7.00000	5.94718	3.00000	2.07846	1.83612	1.85210
43	1.80000	2.59808	2.91442	1.95702	3.25000	2.25167	2.15710	2.63901
44	2.00000	2.88675	---	---	3.50000	2.42487	---	---
45	1.40000	2.02073	---	4.38154	3.75000	2.59808	---	2.24655

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for the items of the Thirty-Five Item Test than for those of the Ten Item Test.

The corresponding results for Case 3 are presented as Tables 4-5 and 4-6, respectively. In all the four situations presented in these two tables, the rescaling of θ was made without excluding any hypothetical subjects, as was the case with those four corresponding situations in Case 2. From the results of Table 4-5 we can say that the estimated guessing parameters are again substantially large for many items whose true difficulty parameters are low. Similar tendencies as those observed for the estimated discrimination and difficulty parameters in Case 2 are also observed in these results of Case 3.

Tables 4-7 and 4-8 present the corresponding results of Case 4. There are additional thirty-five "artificial" test items in these two tables, and they are numbered 46 through 80. In addition to the items referred to earlier, seven more items, i.e., items 46, 47, 74, 76, 78, 79 and 80, in the 500 Subject Case and five more items, i.e., items 46, 47, 78, 79 and 80, in the 2,000 Subject Case had to be excluded either because of the all zero item scores obtained by the examinees, or because of their all unity item scores. Again, no hypothetical examinees were excluded in the process of rescaling θ in Logist 5 in each of the four situations. Although a little less conspicuous, there still appears a tendency that the estimated guessing parameter is substantially large for items having low theoretical difficulty parameters. The estimated discrimination parameters are still "inflated," but they are closer to each other for both situations

TABLE 4-5

Theoretical and Estimated Item Parameters in the 500 and 2,000 Subject Cases for Each Item of the Ten Item Test and the Thirty-Five Item Test. Three-Parameter Logistic Model Is Assumed. Case 3.

Item	Discrimination Parameter				Difficulty Parameter				Guessing Parameter	
	Theoretical		Estimated		Theoretical		Estimated		Estimated	
	Org.	Adj.	500 S.C.	2,000 S.C.	Org.	Adj.	500 S.C.	2,000 S.C.	500 S.C.	2,000 S.C.
1	1.50000	2.16506	7.00000	3.16857	-2.50000	-1.73205	-1.58337	-1.70186	0.31911	0.00000
2	1.00000	1.44338	3.87013	2.20593	-2.00000	-1.38564	-0.82818	-0.99213	0.42360	0.33765
3	2.50000	3.60844	6.61387	6.11440	-1.50000	-1.03923	-0.88235	-0.94942	0.07876	0.06904
4	1.00000	1.44338	1.66601	1.60446	-1.00000	-0.69282	-0.57784	-0.65341	0.06874	0.02886
5	1.50000	2.16506	2.77616	2.49209	-0.50000	-0.34641	-0.27650	-0.33620	0.00000	0.00000
6	1.00000	1.44338	1.55749	1.58121	0.00000	0.00000	0.02360	-0.00453	0.01465	0.00128
7	2.00000	2.88675	2.96359	3.40269	0.50000	0.34641	0.36510	0.36758	0.00000	0.00022
8	1.00000	1.44338	1.76403	1.68448	1.00000	0.69282	0.65648	0.69709	0.00000	0.00000
9	2.00000	2.88675	4.38452	3.69650	1.50000	1.03923	0.97398	0.98698	0.00000	0.00000
10	1.00000	1.44338	1.54466	1.67432	2.00000	1.38564	1.32856	1.35974	0.00000	0.00000
11	1.80000	2.59808	---	---	-4.75000	-3.29090	---	---	---	---
12	1.90000	2.74241	---	---	-4.50000	-3.11769	---	---	---	---
13	2.00000	2.88675	---	---	-4.25000	-2.94449	---	---	---	---
14	1.50000	2.16506	7.00000	2.19806	-4.00000	-2.77128	-2.37410	-2.95371	0.08826	0.10234
15	1.60000	2.30940	---	1.90897	-3.75000	-2.59808	---	-3.36769	---	0.10234
16	1.40000	2.02073	7.00000	1.84048	-3.50000	-2.42487	-2.37226	-2.75675	0.08826	0.10234
17	1.90000	2.74241	2.00167	5.60182	-3.00000	-2.07846	-2.63823	-1.99530	0.08826	0.00000
18	1.80000	2.59808	1.62591	2.21154	-3.00000	-2.07846	-2.57808	-2.29576	0.08826	0.10234
19	1.60000	2.30940	4.45727	2.36176	-2.75000	-1.90526	-1.63765	-1.92579	0.43106	0.10234
20	2.00000	2.88675	6.38769	3.87045	-2.50000	-1.73205	-1.73779	-1.68322	0.00000	0.14877
21	1.50000	2.16506	2.89572	3.06226	-2.25000	-1.55885	-1.57782	-1.50616	0.00000	0.00000
22	1.70000	2.45374	3.03416	4.41425	-2.00000	-1.38564	-1.33087	-1.18774	0.14331	0.20630
23	1.50000	2.16506	3.81430	3.36983	-1.75000	-1.21244	-0.89510	-1.05681	0.28760	0.10975
24	1.40000	2.02073	2.17074	2.43977	-1.50000	-1.03923	-0.87115	-0.92907	0.09159	0.08490
25	2.00000	2.88675	3.70917	3.62242	-1.25000	-0.86603	-0.81486	-0.83289	0.00000	0.01472
26	1.60000	2.30940	2.86861	2.96961	-1.00000	-0.69282	-0.59335	-0.60991	0.00000	0.03712
27	1.80000	2.59808	3.06301	3.14587	-0.75000	-0.51962	-0.41924	-0.50798	0.00089	0.00000
28	1.70000	2.45374	4.17905	3.18564	-0.50000	-0.34641	-0.27372	-0.31965	0.00000	0.00000
29	1.90000	2.74241	3.65756	3.30394	-0.25000	-0.17321	-0.15748	-0.15832	0.00000	0.00000
30	1.70000	2.45374	3.36662	2.92438	0.00000	0.00000	0.05765	0.03296	0.00000	0.00000
31	1.50000	2.16506	2.49791	2.60306	0.25000	0.17321	0.24144	0.16800	0.00000	0.00000
32	1.80000	2.59808	2.97532	3.17624	0.50000	0.34641	0.38466	0.35806	0.00000	0.00000
33	1.40000	2.02073	2.39944	2.24392	0.75000	0.51962	0.49468	0.48257	0.00000	0.00000
34	1.90000	2.74241	3.56410	3.65448	1.00000	0.69282	0.64140	0.65986	0.00000	0.00000
35	2.00000	2.88675	4.31324	3.29432	1.25000	0.86603	0.78225	0.85445	0.00000	0.00000
36	1.60000	2.30940	2.51338	2.56816	1.50000	1.03923	1.01267	1.02876	0.00000	0.00000
37	1.70000	2.45374	2.43304	2.70841	1.75000	1.21244	1.20847	1.22648	0.00000	0.00000
38	1.40000	2.02073	1.99664	2.25976	2.00000	1.38564	1.37635	1.33734	0.00000	0.00000
39	1.90000	2.74241	2.91426	3.11288	2.25000	1.55885	1.47260	1.52379	0.00000	0.00000
40	1.60000	2.30940	3.98169	3.20664	2.50000	1.73205	1.51130	1.63052	0.00000	0.00000
41	1.50000	2.16506	2.40751	2.03311	2.75000	1.90526	2.12160	2.00855	0.00000	0.00000
42	1.70000	2.45374	7.00000	6.06362	3.00000	2.07846	1.86710	1.88062	0.00000	0.00000
43	1.80000	2.59808	2.68843	1.73795	3.25000	2.25167	2.20918	2.79685	0.00000	0.00000
44	2.00000	2.88675	---	---	3.50000	2.42487	---	---	---	---
45	1.40000	2.02073	---	7.00000	3.75000	2.59808	---	2.19260	---	0.00198

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TABLE 4-6

Theoretical and Estimated Item Parameters in the 500 and 2,000 Subject Cases for Each Item of the Ten Item Test and the Thirty-Five Item Test. Logistic Model Is Assumed. Case 3.

Item	Discrimination Parameter				Difficulty Parameter			
	Theoretical		Estimated		Theoretical		Estimated	
	Org.	Adj.	500 S.C.	2,000 S.C.	Org.	Adj.	500 S.C.	2,000 S.C.
1	1.50000	2.16506	4.95337	3.28161	-2.50000	-1.73205	-1.67240	-1.67029
2	1.00000	1.44338	1.69224	1.57696	-2.00000	-1.38564	-1.36571	-1.35902
3	2.50000	3.60844	4.07728	4.17736	-1.50000	-1.03923	-1.01281	-1.02694
4	1.00000	1.44338	1.46003	1.53778	-1.00000	-0.69282	-0.70019	-0.70004
5	1.50000	2.16506	2.68987	2.47682	-0.50000	-0.34641	-0.30131	-0.34419
6	1.00000	1.44338	1.44917	1.55961	0.00000	0.00000	-0.01392	-0.00994
7	2.00000	2.88675	2.86243	3.32482	0.50000	0.34641	0.36627	0.36951
8	1.00000	1.44338	1.72479	1.67575	1.00000	0.69282	0.66329	0.70095
9	2.00000	2.88675	4.34492	3.69979	1.50000	1.03923	0.98918	0.99343
10	1.00000	1.44338	1.53441	1.68119	2.00000	1.38564	1.34230	1.36275
11	1.80000	2.59808	---	---	-4.75000	-3.29090	---	---
12	1.90000	2.74241	---	---	-4.50000	-3.11769	---	---
13	2.00000	2.88675	---	---	-4.25000	-2.94449	---	---
14	1.50000	2.16506	7.00000	2.91928	-4.00000	-2.77128	-2.15752	-2.60081
15	1.60000	2.30940	---	1.74182	-3.75000	-2.59808	---	-3.53483
16	1.40000	2.02073	7.00000	2.09438	-3.50000	-2.42487	-2.15752	-2.60017
17	1.90000	2.74241	2.73182	5.71243	-3.00000	-2.07846	-2.32255	-1.91514
18	1.80000	2.59808	1.93571	2.41736	-3.00000	-2.07846	-2.37937	-2.22083
19	1.60000	2.30940	2.78781	2.41276	-2.75000	-1.90526	-1.85334	-1.92091
20	2.00000	2.88675	7.00000	3.84414	-2.50000	-1.73205	-1.66676	-1.69924
21	1.50000	2.16506	3.05070	3.28211	-2.25000	-1.55885	-1.54605	-1.48938
22	1.70000	2.45374	2.81049	3.11682	-2.00000	-1.38564	-1.42047	-1.33659
23	1.50000	2.16506	2.18879	2.84317	-1.75000	-1.21244	-1.22508	-1.15676
24	1.40000	2.02073	1.98367	2.16013	-1.50000	-1.03923	-0.99519	-1.02270
25	2.00000	2.88675	3.78513	3.38927	-1.25000	-0.86603	-0.85820	-0.86525
26	1.60000	2.30940	2.79550	2.57449	-1.00000	-0.69282	-0.63042	-0.66551
27	1.80000	2.59808	2.94721	3.13646	-0.75000	-0.51962	-0.45199	-0.51928
28	1.70000	2.45374	4.01387	3.15357	-0.50000	-0.34641	-0.29894	-0.32714
29	1.90000	2.74241	3.47887	3.27011	-0.25000	-0.17321	-0.17677	-0.16301
30	1.70000	2.45374	3.26431	2.89248	0.00000	0.00000	0.04783	0.03087
31	1.50000	2.16506	2.41301	2.57220	0.25000	0.17321	0.23779	0.16763
32	1.80000	2.59808	2.87394	3.12995	0.50000	0.34641	0.38646	0.36035
33	1.40000	2.02073	2.34406	2.22892	0.75000	0.51962	0.49893	0.48570
34	1.90000	2.74241	3.47064	3.61903	1.00000	0.69282	0.65094	0.66576
35	2.00000	2.88675	4.20559	3.28752	1.25000	0.86603	0.79511	0.86083
36	1.60000	2.30940	2.49622	2.58101	1.50000	1.03923	1.02635	1.03417
37	1.70000	2.45374	2.42736	2.72468	1.75000	1.21244	1.22281	1.23107
38	1.40000	2.02073	1.99253	2.27881	2.00000	1.38564	1.39037	1.34037
39	1.90000	2.74241	2.94510	3.18444	2.25000	1.55885	1.48530	1.52314
40	1.60000	2.30940	3.99991	3.23204	2.50000	1.73205	1.52512	1.63091
41	1.50000	2.16506	2.40032	2.03234	2.75000	1.90526	2.13695	2.01093
42	1.70000	2.45374	7.00000	6.04216	3.00000	2.07846	1.87981	1.87873
43	1.80000	2.59808	2.70006	1.73892	3.25000	2.25167	2.22019	2.79913
44	2.00000	2.88675	---	---	3.50000	2.42487	---	---
45	1.40000	2.02073	---	4.00385	3.75000	2.59808	---	2.31592

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TABLE 4-7

Theoretical and Estimated Item Parameters in the 500 and 2,000 Subject Cases for Each Item of the Ten Item Test, Thirty-Five Item Test and the Additional Set of Thirty-Five Items. Three-Parameter Logistic Model Is Assumed. Case 4.

Item	Discrimination Parameter				Difficulty Parameter				Guessing Parameter	
	Theoretical		Estimated		Theoretical		Estimated		Estimated	
	Org.	Adj.	500 S.C.	2,000 S.C.	Org.	Adj.	500 S.C.	2,000 S.C.	500 S.C.	2,000 S.C.
1	1.50000	2.16506	3.41434	3.00167	-2.50000	-1.73205	-1.72520	-1.69465	0.00000	0.00000
2	1.00000	1.44338	3.29077	2.22717	-2.00000	-1.38564	-0.89904	-0.96868	0.40489	0.36573
3	2.50000	3.60844	4.26469	4.77358	-1.50000	-1.03923	-0.96121	-0.97525	0.04764	0.06512
4	1.00000	1.44338	1.49235	1.50609	-1.00000	-0.69282	-0.67263	-0.69374	0.02109	0.00572
5	1.50000	2.16506	2.69878	2.44557	-0.50000	-0.34641	-0.30645	-0.33458	0.00000	0.00473
6	1.00000	1.44338	1.45554	1.52362	0.00000	0.00000	-0.01051	-0.00980	0.00570	0.00000
7	2.00000	2.88675	2.81255	3.17229	0.50000	0.34641	0.35161	0.36437	0.00000	0.00000
8	1.00000	1.44338	1.61952	1.62062	1.00000	0.69282	0.66487	0.70467	0.00000	0.00000
9	2.00000	2.88675	3.88949	3.20578	1.50000	1.03923	1.00246	1.00496	0.00000	0.00000
10	1.00000	1.44338	1.49731	1.64327	2.00000	1.38564	1.35617	1.37264	0.00000	0.00000
11	1.80000	2.59808	---	---	-4.75000	-3.29090	---	---	---	---
12	1.90000	2.74241	---	---	-4.50000	-3.11769	---	---	---	---
13	2.00000	2.88675	---	---	-4.25000	-2.94449	---	---	---	---
14	1.50000	2.16506	7.00000	3.91266	-4.00000	-2.77128	-2.20782	-2.39100	0.00000	0.03468
15	1.60000	2.30940	---	2.18301	-3.75000	-2.59808	---	-3.12545	---	0.03468
16	1.40000	2.02073	7.00000	2.33617	-3.50000	-2.42487	-2.03372	-2.48901	0.50000	0.03468
17	1.90000	2.74241	3.35799	7.00000	-3.00000	-2.07846	-2.18794	-1.84693	0.11111	0.21436
18	1.80000	2.59808	2.25841	2.48088	-3.00000	-2.07846	-2.22797	-2.19957	0.11111	0.03468
19	1.60000	2.30940	6.56632	2.61144	-2.75000	-1.90526	-1.51892	-1.88161	0.50000	0.03468
20	2.00000	2.88675	4.32458	3.20291	-2.50000	-1.73205	-1.71620	-1.74176	0.00000	0.00000
21	1.50000	2.16506	3.10876	3.26381	-2.25000	-1.55885	-1.53891	-1.49560	0.00000	0.00000
22	1.70000	2.45374	2.61890	3.41314	-2.00000	-1.38564	-1.42058	-1.26670	0.00000	0.12604
23	1.50000	2.16506	2.82639	3.17517	-1.75000	-1.21244	-1.07270	-1.08862	0.15690	0.09335
24	1.40000	2.02073	2.06636	2.37464	-1.50000	-1.03923	-0.95700	-0.94428	0.03176	0.08417
25	2.00000	2.88675	3.57829	3.13381	-1.25000	-0.86603	-0.85408	-0.86278	0.00000	0.00000
26	1.60000	2.30940	2.87736	2.89571	-1.00000	-0.69282	-0.62853	-0.61657	0.00000	0.03865
27	1.80000	2.59808	3.03750	2.96977	-0.75000	-0.51962	-0.45344	-0.51406	0.00000	0.00000
28	1.70000	2.45374	3.73453	2.97059	-0.50000	-0.34641	-0.30369	-0.32323	0.00000	0.00000
29	1.90000	2.74241	3.46935	3.24521	-0.25000	-0.17321	-0.18461	-0.16184	0.00000	0.00000
30	1.70000	2.45374	3.11959	2.89623	0.00000	0.00000	0.03454	0.02895	0.00000	0.00000
31	1.50000	2.16506	2.34512	2.50594	0.25000	0.17321	0.22502	0.16486	0.00000	0.00000
32	1.80000	2.59808	2.77677	3.00145	0.50000	0.34641	0.37223	0.35562	0.00000	0.00000
33	1.40000	2.02073	2.26261	2.15307	0.75000	0.51962	0.49043	0.48439	0.00000	0.00000
34	1.90000	2.74241	3.27880	3.32280	1.00000	0.69282	0.64569	0.66430	0.00000	0.00000
35	2.00000	2.88675	3.49907	3.02911	1.25000	0.86603	0.79919	0.86670	0.00000	0.00000

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36	1.60000	2.30940	2.26400	2.42606	1.50000	1.03923	1.04124	1.04434	0.00000	0.00000
37	1.70000	2.45374	2.46372	2.65747	1.75000	1.21244	1.23076	1.24084	0.00000	0.00000
38	1.40000	2.02073	2.01719	2.18450	2.00000	1.38564	1.39610	1.35317	0.00000	0.00000
39	1.90000	2.74241	2.69649	2.83214	2.25000	1.55885	1.51261	1.54567	0.00000	0.00000
40	1.60000	2.30940	3.55183	3.36066	2.50000	1.73205	1.55239	1.62235	0.00000	0.00000
41	1.50000	2.16506	1.90045	2.09162	2.75000	1.90526	2.29982	1.98522	0.00000	0.00000
42	1.70000	2.45374	7.00000	6.49245	3.00000	2.07846	1.85903	1.83539	0.00000	0.00000
43	1.80000	2.59808	2.22398	1.89946	3.25000	2.25167	2.34661	2.66871	0.00000	0.00000
44	2.00000	2.88675	---	---	3.50000	2.42487	---	---	---	---
45	1.40000	2.02073	---	3.53540	3.75000	2.59808	---	2.31707	---	0.00000
46	1.80000	2.59808	---	---	-3.75000	-2.59808	---	---	---	---
47	1.90000	2.74241	---	---	-3.50000	-2.42487	---	---	---	---
48	2.00000	2.88675	1.65615	2.48879	-3.25000	-2.25167	-2.89607	-2.46680	0.11111	0.03468
49	1.50000	2.16506	3.93845	2.11207	-3.00000	-2.07846	-1.95551	-2.26065	0.11111	0.03468
50	1.60000	2.30940	2.16634	3.30824	-2.75000	-1.90526	-2.00139	-1.60750	0.11111	0.50000
51	1.40000	2.02073	2.13178	2.73921	-2.50000	-1.73205	-1.71598	-1.51070	0.00000	0.27038
52	1.90000	2.74241	2.94297	3.13930	-2.00000	-1.38564	-1.42593	-1.42137	0.00000	0.00000
53	1.80000	2.59808	2.99335	3.04155	-2.00000	-1.38564	-1.20128	-1.30253	0.16075	0.08424
54	1.60000	2.30940	2.51813	2.56022	-1.75000	-1.21244	-1.19173	-1.22079	0.00000	0.00000
55	2.00000	2.88675	3.52683	3.56459	-1.50000	-1.03923	-0.97971	-0.98982	0.00220	0.00000
56	1.50000	2.16506	2.15083	2.45531	-1.25000	-0.86603	-0.81208	-0.86009	0.01728	0.00000
57	1.70000	2.45374	3.16197	2.83349	-1.00000	-0.69282	-0.59935	-0.67167	0.01181	0.00000
58	1.50000	2.16506	2.56946	2.43801	-0.75000	-0.51962	-0.49076	-0.51983	0.00000	0.00000
59	1.40000	2.02073	2.47960	2.50390	-0.50000	-0.34641	-0.30105	-0.31697	0.00000	0.00000
60	2.00000	2.88675	2.94042	3.29908	-0.25000	-0.17321	-0.15217	-0.15679	0.00000	0.00000
61	1.60000	2.30940	2.92132	2.52572	0.00000	0.00000	-0.01023	0.02219	0.00000	0.00000
62	1.80000	2.59808	2.85132	2.99588	0.25000	0.17321	0.21551	0.20297	0.00000	0.00000
63	1.70000	2.45374	2.62639	2.74542	0.50000	0.34641	0.31140	0.33140	0.00000	0.00000
64	1.90000	2.74241	3.04783	3.06757	0.75000	0.51962	0.53653	0.54103	0.00000	0.00000
65	1.70000	2.45374	3.18272	2.89775	1.00000	0.69282	0.67249	0.66449	0.00000	0.00000
66	1.50000	2.16506	2.70700	2.48166	1.25000	0.86603	0.83533	0.85440	0.00000	0.00000
67	1.80000	2.59808	3.02039	3.41981	1.50000	1.03923	0.96838	1.02375	0.00000	0.00000
68	1.40000	2.02073	2.34530	2.36776	1.75000	1.21244	1.25342	1.16936	0.00000	0.00000
69	1.90000	2.74241	2.86873	3.24824	2.00000	1.38564	1.34379	1.35137	0.00000	0.00000
70	2.00000	2.88675	3.04314	2.87183	2.25000	1.55885	1.48181	1.52512	0.00000	0.00000
71	1.60000	2.30940	4.58205	3.17071	2.50000	1.73205	1.60055	1.66385	0.00000	0.00000
72	1.70000	2.45374	2.87135	3.68760	2.75000	1.90526	1.87762	1.83679	0.00000	0.00000
73	1.40000	2.02073	7.00000	2.70660	3.00000	2.07846	1.92387	2.05018	0.01188	0.00000
74	1.90000	2.74241	---	7.00000	3.25000	2.25167	---	2.06124	---	0.00000
75	1.60000	2.30940	2.95348	3.20156	3.50000	2.42487	2.45972	2.33965	0.00000	0.00000
76	1.50000	2.16506	---	3.62677	3.75000	2.59808	---	2.53398	---	0.00000
77	1.70000	2.45374	7.00000	6.87045	4.00000	2.77128	2.09473	2.14071	0.00000	0.00000
78	1.80000	2.59808	---	---	4.25000	2.94449	---	---	---	---
79	2.00000	2.88675	---	---	4.50000	3.11769	---	---	---	---
80	1.40000	2.02073	---	---	4.75000	3.29090	---	---	---	---

TABLE 4-8

Theoretical and Estimated Item Parameters in the 500 and 2,000 Subject Cases for Each Item of the Ten Item Test, Thirty-Five Item Test and the Additional Set of Thirty-Five Items. Logistic Model Is Assumed. Case 4.

Item	Discrimination Parameter				Difficulty Parameter			
	Theoretical		Estimated		Theoretical		Estimated	
	Org.	Adj.	500 S.C.	2,000 S.C.	Org.	Adj.	500 S.C.	2,000 S.C.
1	1.50000	2.16506	3.72684	3.07028	-2.50000	-1.73205	-1.69210	-1.68238
2	1.00000	1.44338	1.65223	1.52731	-2.00000	-1.38564	-1.36793	-1.37154
3	2.50000	3.60844	3.59656	3.70406	-1.50000	-1.03923	-1.01728	-1.03414
4	1.00000	1.44338	1.44195	1.49512	-1.00000	-0.69282	-0.70755	-0.70424
5	1.50000	2.16506	2.67224	2.38228	-0.50000	-0.34641	-0.31213	-0.34367
6	1.00000	1.44338	1.41840	1.51732	0.00000	0.00000	-0.02249	-0.01020
7	2.00000	2.88675	2.78154	3.15697	0.50000	0.34641	0.35386	0.36679
8	1.00000	1.44338	1.60933	1.62039	1.00000	0.69282	0.66845	0.70644
9	2.00000	2.88675	3.86351	3.22524	1.50000	1.03923	1.00912	1.00685
10	1.00000	1.44338	1.50703	1.65231	2.00000	1.38564	1.35715	1.37203
11	1.80000	2.59808	---	---	-4.75000	-3.29090	---	---
12	1.90000	2.74241	---	---	-4.50000	-3.11769	---	---
13	2.00000	2.88675	---	---	-4.25000	-2.94449	---	---
14	1.50000	2.16506	7.00000	4.18964	-4.00000	-2.77128	-2.12460	-2.30785
15	1.60000	2.30940	---	2.26449	-3.75000	-2.59808	---	-3.05746
16	1.40000	2.02073	4.93831	2.48782	-3.50000	-2.42487	-2.21029	-2.42230
17	1.90000	2.74241	3.80449	7.00000	-3.00000	-2.07846	-2.12493	-1.85373
18	1.80000	2.59808	2.44437	2.62452	-3.00000	-2.07846	-2.18906	-2.15717
19	1.60000	2.30940	3.05923	2.65246	-2.75000	-1.90526	-1.80634	-1.87546
20	2.00000	2.88675	4.53018	3.38488	-2.50000	-1.73205	-1.68883	-1.71972
21	1.50000	2.16506	3.21950	3.34875	-2.25000	-1.55885	-1.52729	-1.49074
22	1.70000	2.45374	2.75628	3.01913	-2.00000	-1.38564	-1.41352	-1.34519
23	1.50000	2.16506	2.36370	2.77310	-1.75000	-1.21244	-1.21285	-1.16388
24	1.40000	2.02073	2.00406	2.11082	-1.50000	-1.03923	-0.99610	-1.02829
25	2.00000	2.88675	3.57138	3.13369	-1.25000	-0.86603	-0.86755	-0.86954
26	1.60000	2.30940	2.84127	2.51903	-1.00000	-0.69282	-0.63886	-0.66645
27	1.80000	2.59808	2.99887	2.95792	-0.75000	-0.51962	-0.46131	-0.51804
28	1.70000	2.45374	3.66463	2.95891	-0.50000	-0.34641	-0.30923	-0.32549
29	1.90000	2.74241	3.41412	3.23105	-0.25000	-0.17321	-0.18852	-0.16273
30	1.70000	2.45374	3.09273	2.88274	0.00000	0.00000	0.03311	0.02941
31	1.50000	2.16506	2.31939	2.49396	0.25000	0.17321	0.22567	0.16600
32	1.80000	2.59808	2.74806	2.99118	0.50000	0.34641	0.37470	0.35793
33	1.40000	2.02073	2.24698	2.15137	0.75000	0.51962	0.49371	0.48654
34	1.90000	2.74241	3.25685	3.32014	1.00000	0.69282	0.65121	0.66740
35	2.00000	2.88675	3.46982	3.04180	1.25000	0.86603	0.80565	0.86921

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36	1.60000	2.30940	2.26525	2.43695	1.50000	1.03923	1.04618	1.04584
37	1.70000	2.45374	2.49287	2.67665	1.75000	1.21244	1.23358	1.24116
38	1.40000	2.02073	2.03327	2.19706	2.00000	1.38564	1.39735	1.35292
39	1.90000	2.74241	2.73122	2.85681	2.25000	1.55885	1.51178	1.54391
40	1.60000	2.30940	3.60493	3.36654	2.50000	1.73205	1.55051	1.62142
41	1.50000	2.16506	1.96429	2.09506	2.75000	1.90526	2.27272	1.98431
42	1.70000	2.45374	7.00000	6.25673	3.00000	2.07846	1.85406	1.83992
43	1.80000	2.59808	2.24123	1.89216	3.25000	2.25167	2.33998	2.67372
44	2.00000	2.88675	---	---	3.50000	2.42487	---	---
45	1.40000	2.02073	---	3.44390	3.75000	2.59808	---	2.33500
46	1.80000	2.59808	---	---	-3.75000	-2.59808	---	---
47	1.90000	2.74241	---	---	-3.50000	-2.42487	---	---
48	2.00000	2.88675	1.65181	2.77341	-3.25000	-2.25167	-2.92148	-2.36388
49	1.50000	2.16506	4.29085	2.19098	-3.00000	-2.07846	-1.92503	-2.23043
50	1.60000	2.30940	2.15004	2.64628	-2.75000	-1.90526	-2.02814	-1.87139
51	1.40000	2.02073	2.26422	2.46143	-2.50000	-1.73205	-1.68791	-1.65402
52	1.90000	2.74241	3.11145	3.20821	-2.00000	-1.38564	-1.41906	-1.41957
53	1.80000	2.59808	2.53858	2.88308	-2.00000	-1.38564	-1.32469	-1.35346
54	1.60000	2.30940	2.56117	2.57874	-1.75000	-1.21244	-1.19716	-1.22428
55	2.00000	2.88675	3.53579	3.56475	-1.50000	-1.03923	-0.99484	-0.99738
56	1.50000	2.16506	2.08227	2.45651	-1.25000	-0.86603	-0.84039	-0.86580
57	1.70000	2.45374	2.93475	2.81444	-1.00000	-0.69282	-0.62403	-0.67700
58	1.50000	2.16506	2.55209	2.42151	-0.75000	-0.51962	-0.49880	-0.52372
59	1.40000	2.02073	2.45314	2.48398	-0.50000	-0.34641	-0.30666	-0.31923
60	2.00000	2.88675	2.92942	3.28162	-0.25000	-0.17321	-0.15584	-0.15762
61	1.60000	2.30940	2.89170	2.50830	0.00000	0.00000	-0.01218	0.02247
62	1.80000	2.59808	2.82379	2.98334	0.25000	0.17321	0.21617	0.20454
63	1.70000	2.45374	2.59042	2.72777	0.50000	0.34641	0.31316	0.33348
64	1.90000	2.74241	3.01309	3.06215	0.75000	0.51962	0.54090	0.54394
65	1.70000	2.45374	3.15705	2.90078	1.00000	0.69282	0.67811	0.66738
66	1.50000	2.16506	2.69905	2.48647	1.25000	0.86603	0.84115	0.85672
67	1.80000	2.59808	3.06261	3.43685	1.50000	1.03923	0.97402	1.02562
68	1.40000	2.02073	2.38477	2.37751	1.75000	1.21244	1.25516	1.17030
69	1.90000	2.74241	2.87444	3.25895	2.00000	1.38564	1.34676	1.35142
70	2.00000	2.88675	3.07327	2.88669	2.25000	1.55885	1.48189	1.52410
71	1.60000	2.30940	4.65176	3.18260	2.50000	1.73205	1.59754	1.66249
72	1.70000	2.45374	2.93033	3.68052	2.75000	1.90526	1.86943	1.83665
73	1.40000	2.02073	3.03207	2.69563	3.00000	2.07846	2.05377	2.05217
74	1.90000	2.74241	---	7.00000	3.25000	2.25167	---	2.06555
75	1.60000	2.30940	2.97866	3.09922	3.50000	2.42487	2.45256	2.36309
76	1.50000	2.16506	---	3.44436	3.75000	2.59808	---	2.57899
77	1.70000	2.45374	7.00000	6.45131	4.00000	2.77128	2.09808	2.16256
78	1.80000	2.59808	---	---	4.25000	2.94449	---	---
79	2.00000	2.88675	---	---	4.50000	3.11769	---	---
80	1.40000	2.02073	---	---	4.75000	3.29090	---	---

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in which the three-parameter logistic model and the logistic model were assumed, respectively.

The enhancement of the estimated discrimination parameters is more revealing if we plot those values against the theoretical discrimination parameters a_g. Figures 4-1 through 4-4 present those results in the 500 Subject Case when we assumed the three-parameter logistic model and the logistic model, respectively, for Cases 1, 2, 3 and 4. In each of these graphs, the upper limits set for the estimated discrimination parameter in using Logist 5 are indicated by a dotted, horizontal line. Also a solid line with the angle of 45 degrees from the abscissa passing (0,0) is drawn in each graph. We can see in these results that, although there is some improvement in those obtained by setting $c_g = 0.0$ in using Logist 5, many discrimination parameters are outrageously overestimated. The corresponding results in the 2,000 Subject Case are presented as Figures 4-5 through 4-8 for Cases 1, 2, 3 and 4, respectively. These results are fairly similar to those in the 500 Subject Case, although we can see some improvement for the result of this larger subject group. The correlation between the estimated and the true discrimination parameters appears to increase as the number of hypothetical test items increases. When the number of items is as small as thirty-five, however, there does not seem to be any positive correlation between these two sets of values.

The corresponding results on the difficulty parameters in the 500 Subject Case are presented in the eight graphs of Figures 4-9 through 4-12, and those in the 2,000 Subject Case are given in the

eight graphs of Figures 4-13 through 4-16.* In these graphs, the interval of θ, $(-\sqrt{3}, \sqrt{3})$, for which the ability distribution is uniform, is indicated by two solid, vertical lines. We can see in these figures that, with the exception of Case 1, a strong positive correlation is indicated between the estimated and the theoretical difficulty parameters, especially for the subset of items whose theoretical difficulty parameters are within the interval, $(-\sqrt{3}, \sqrt{3})$. Some improvement is observed in the results obtained by assuming the logistic model compared with those obtained by assuming the three-parameter logistic model, both in the 500 Subject Case and in the 2,000 Case in each of the Cases 1, 2, 3 and 4.

Those results on the difficulty parameter estimation suggest that the "outrageous" overestimation of the discrimination parameter may partly be due to the lack of examinees in the range of θ at which the discrimination power of the item is maximal, i.e., around the difficulty parameter b_g. In order to investigate this, we replotted the estimated discrimination parameters against the theoretical discrimination parameters for the subset of items whose theoretical difficulty parameters are within the interval $(-\sqrt{3}, \sqrt{3})$ only. There are nine such items in Case 1, i.e., items 2 through 10, nineteen items in Case 2, i.e., items 21 through 39, twenty-eight items in Case 3 combining those two subsets of items, and forty-seven

*In each of these graphs, for the purpose of reference, a dotted line representing the linear regression, or the line fitted by the least squares principle, of $\hat{\theta}$ on θ is drawn, together with a solid line diverging the abscissa with the angle of 45 degrees. Note that this linear regression is of $\hat{\theta}$ on θ, which is to be introduced in Section 8.

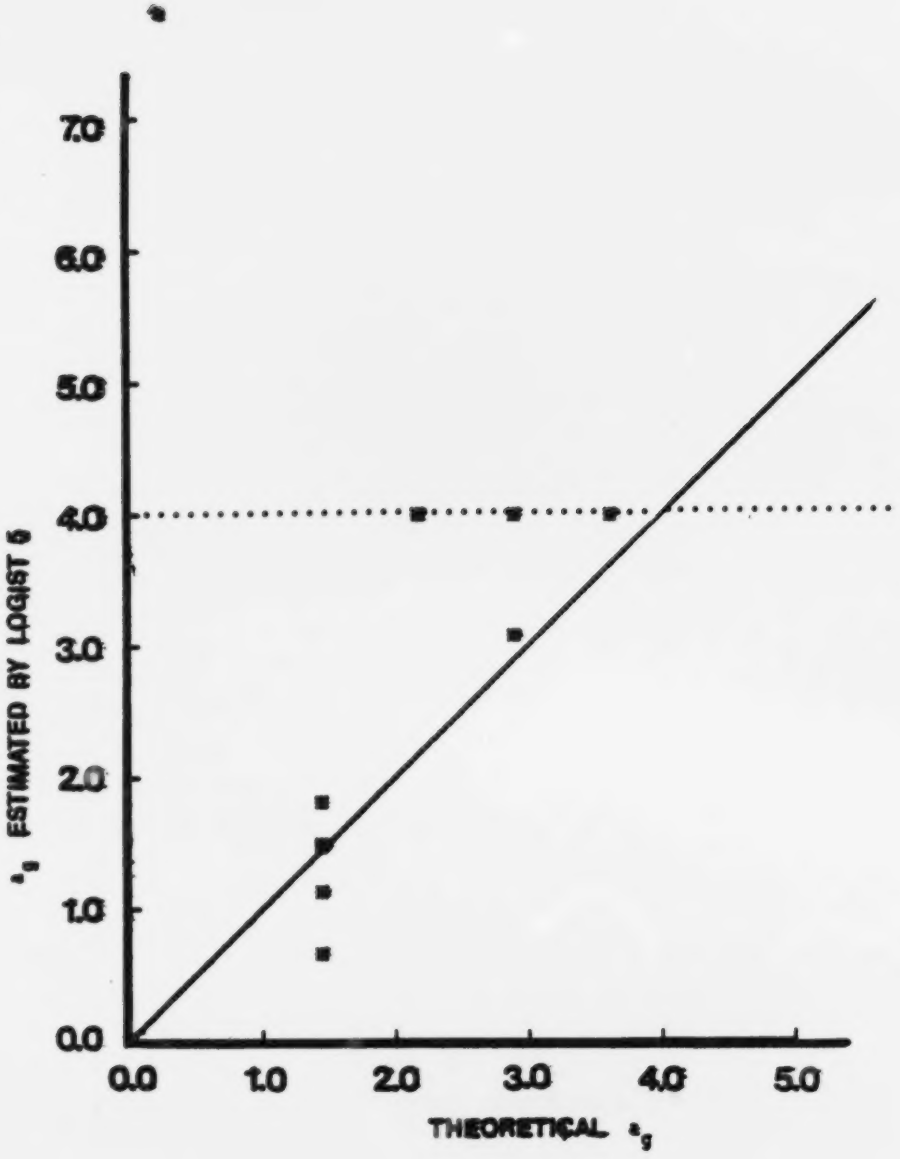

FIGURE 4-1

Estimated Discrimination Parameter Obtained by LOGIST 5 Plotted against the True Discrimination Parameter a_g for Each Item of the Ten Item Test (■). Case 1, 500 Subject Case.

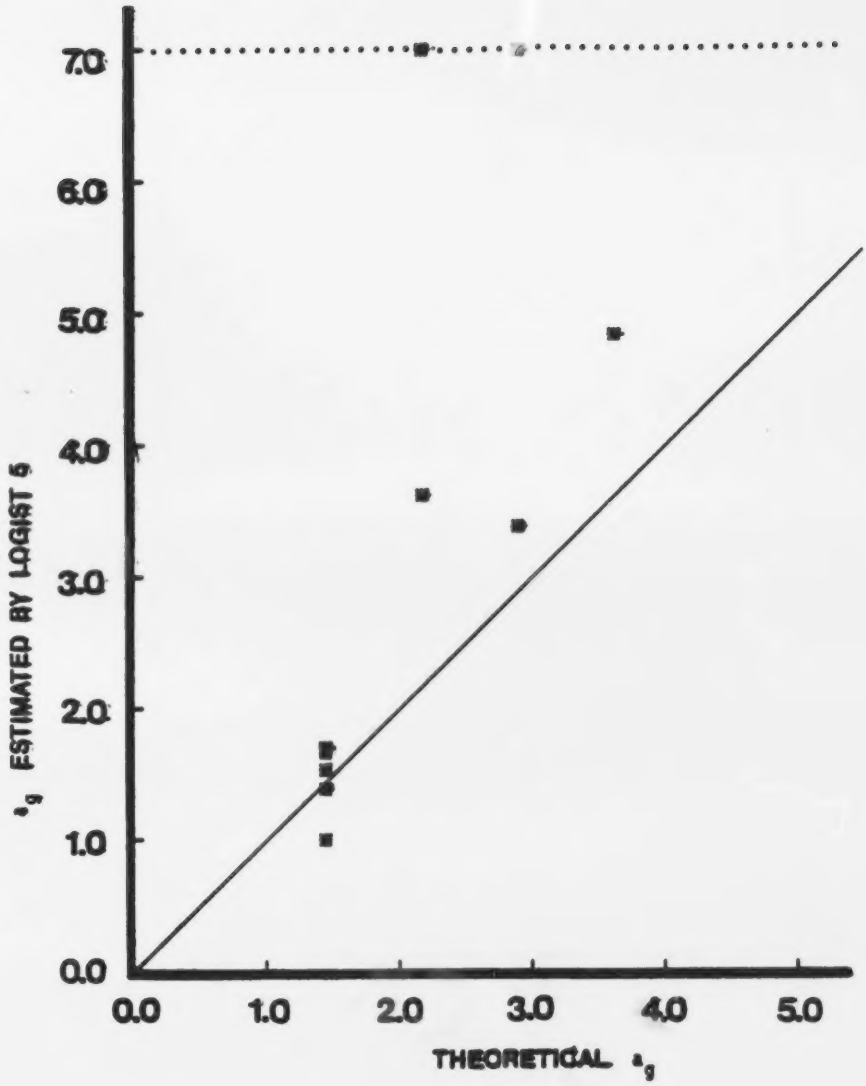

FIGURE 4-1 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

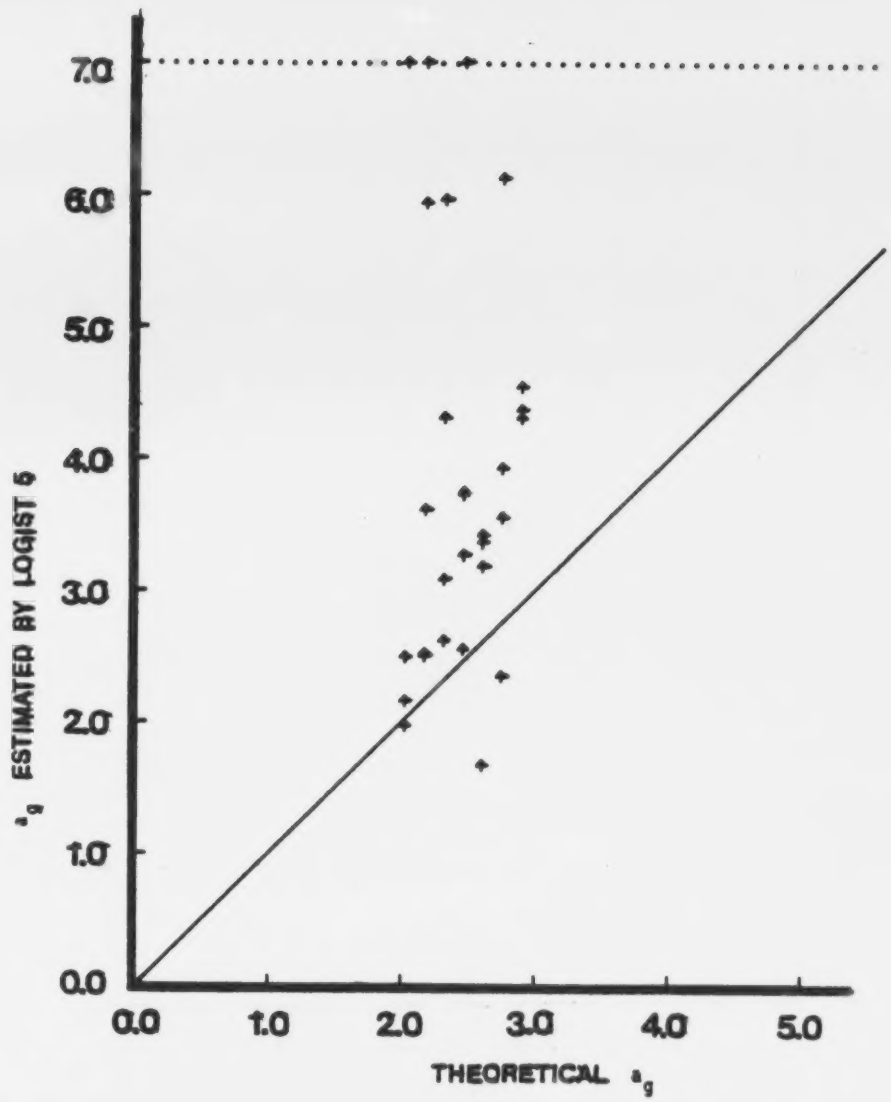

FIGURE 4-2

Estimated Discrimination Parameter Obtained by LOGIST 5 Plotted against the True Discrimination Parameter a_g for Each Item of the Thirty-Five Item Test (♦). Case 2, 500 Subject Case.

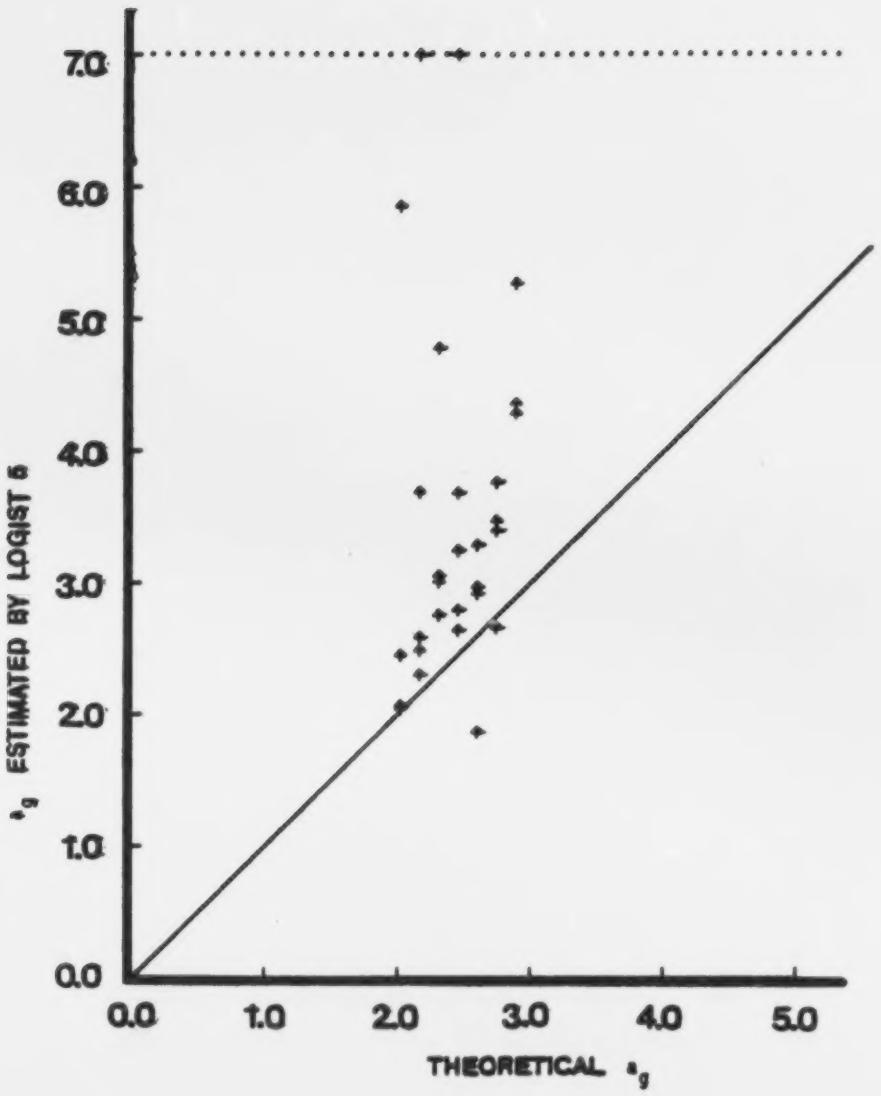

FIGURE 4-2 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

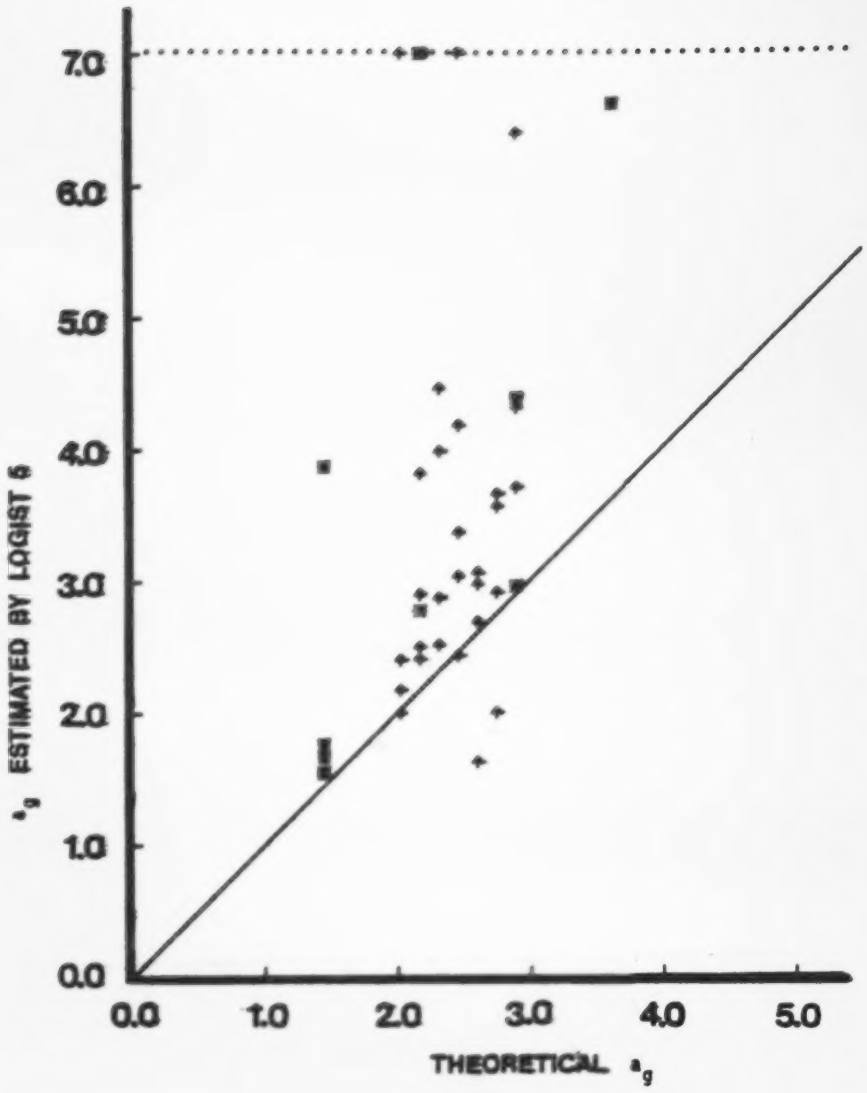

FIGURE 4-3

Estimated Discrimination Parameter Obtained by LOGIST 5 Plotted against the True Discrimination Parameter a_g for Each Item of the Ten Item Test (■) and of the Thirty-Five Item Test (✦). Case 3, 500 Subject Case.

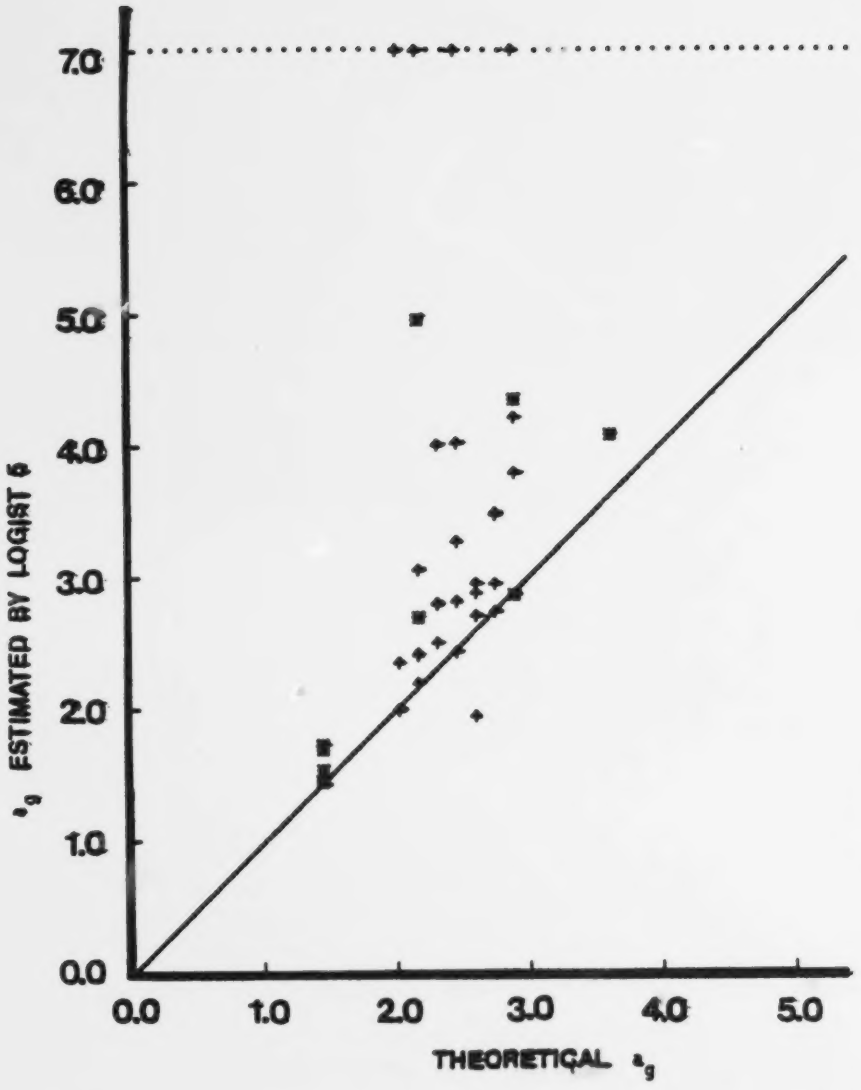

FIGURE 4-3 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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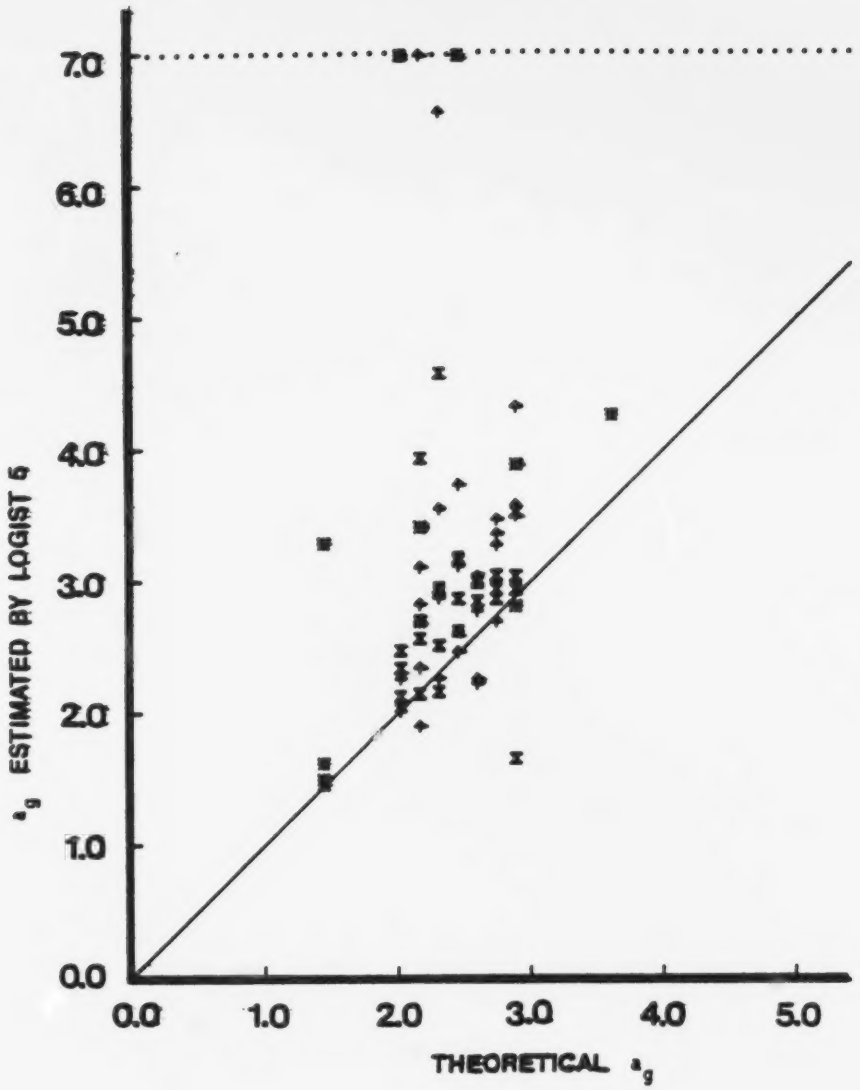

FIGURE 4-4

Estimated Discrimination Parameter Obtained by LOGIST 5 Plotted against the True Discrimination Parameter a_g for Each Item of the Ten Item Test (■) and of the Thirty-Five Item Test (✦) and Each of the Additional Thirty-Five Items (⧗). Case 4, 500 Subject Case.

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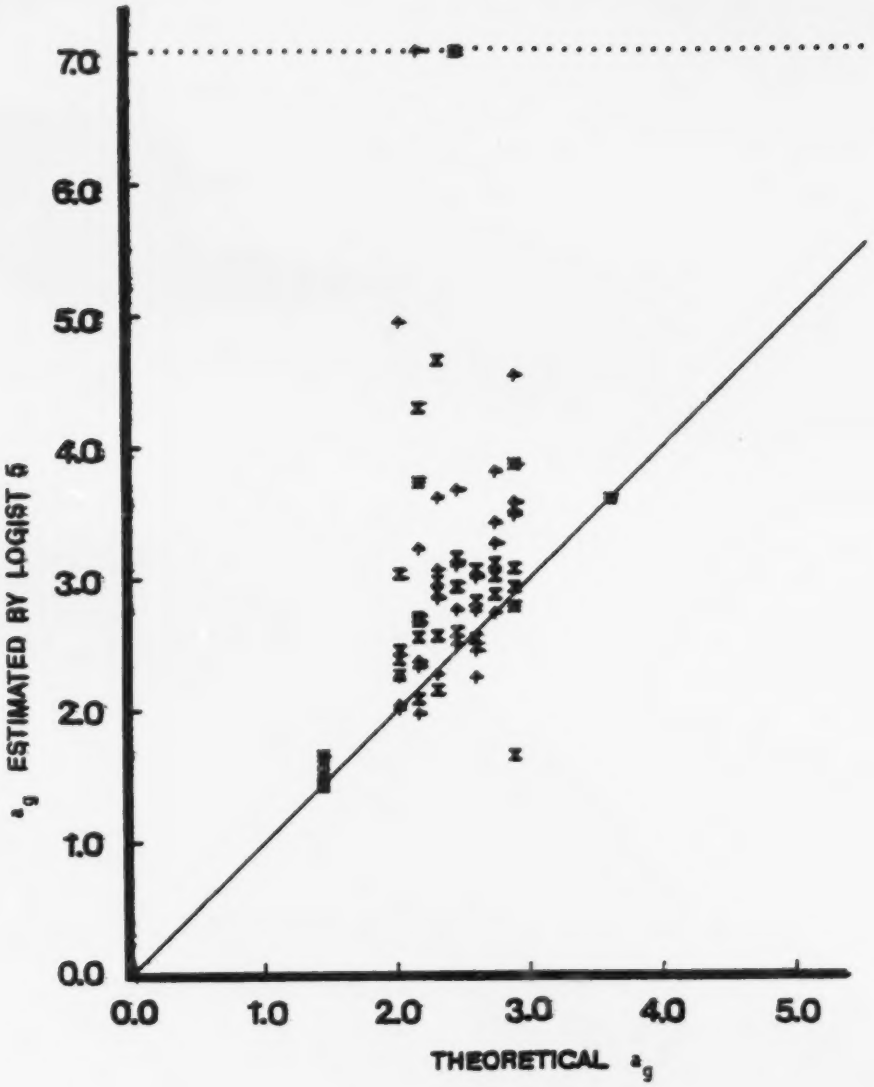

FIGURE 4-4 (continued) : Guessing Parameter c_g Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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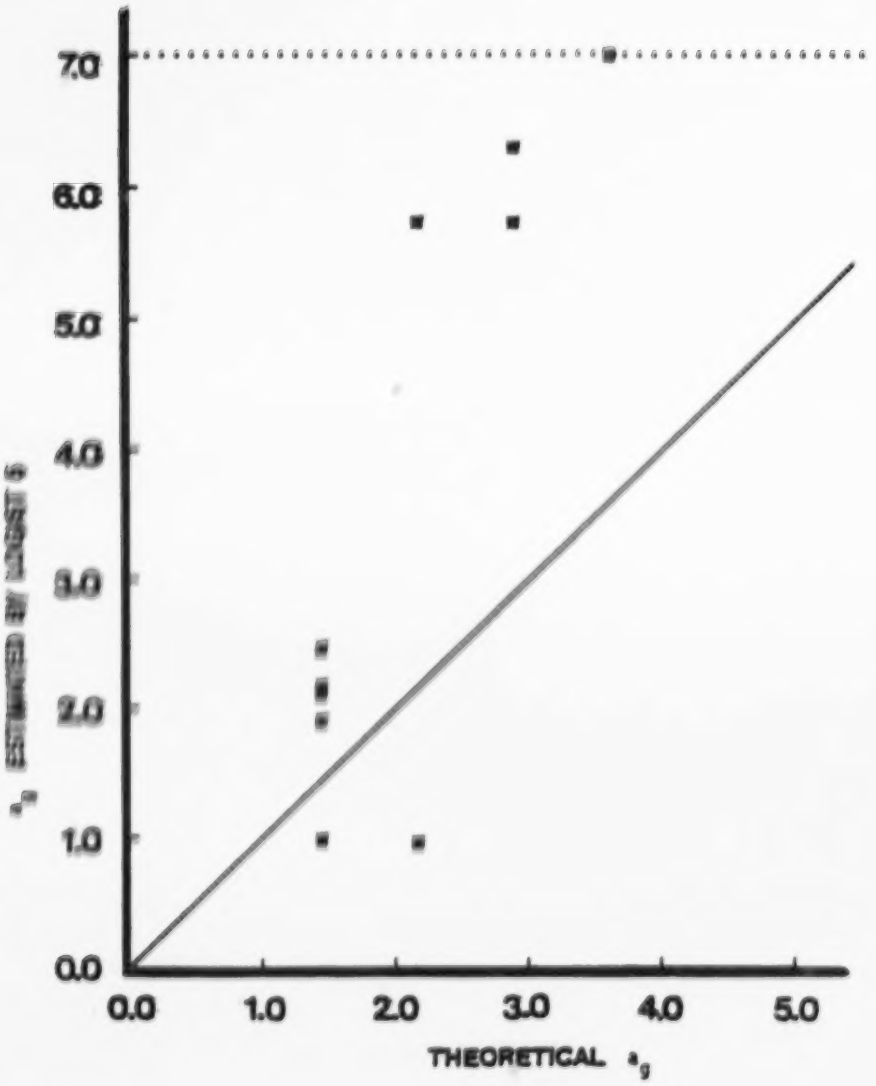

FIGURE 4-5

Estimated Discrimination Parameter Obtained by LOGIST 5 Plotted against the True Discrimination Parameter a_g for Each Item of the Ten Item Test (M), Base 1 of 5,000 Subject Cases.

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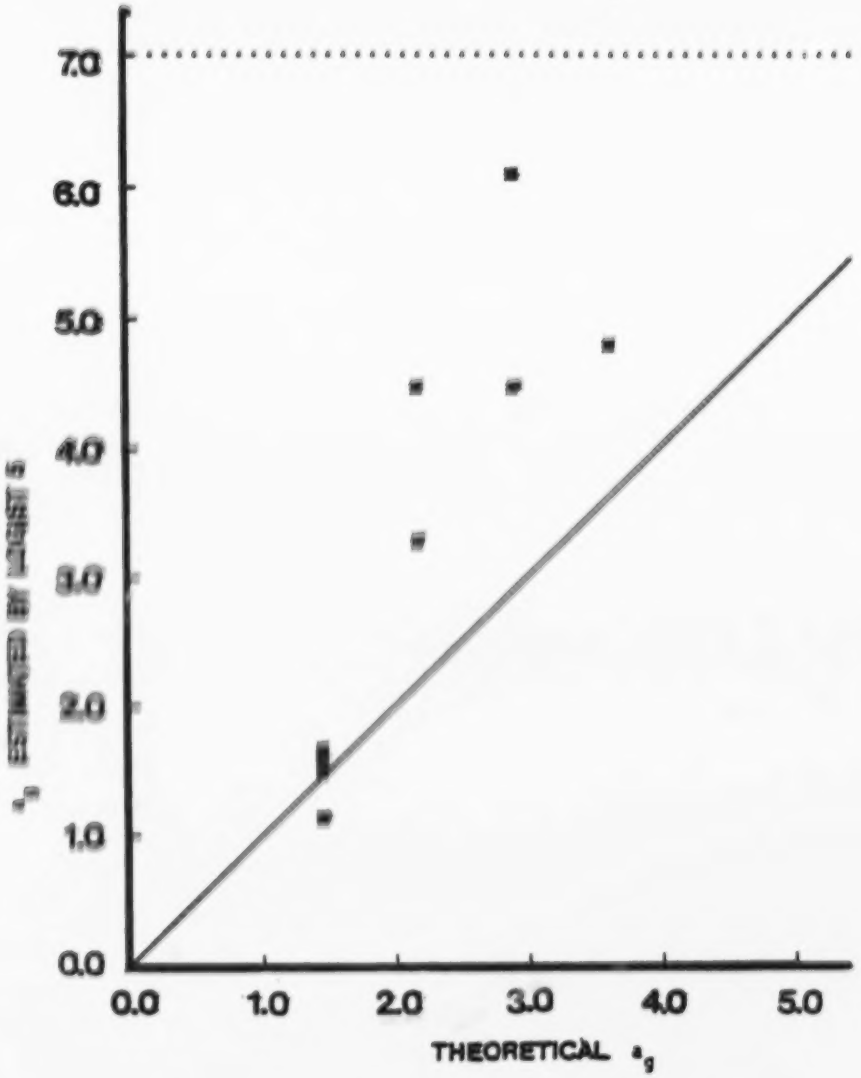

FIGURE 4-5 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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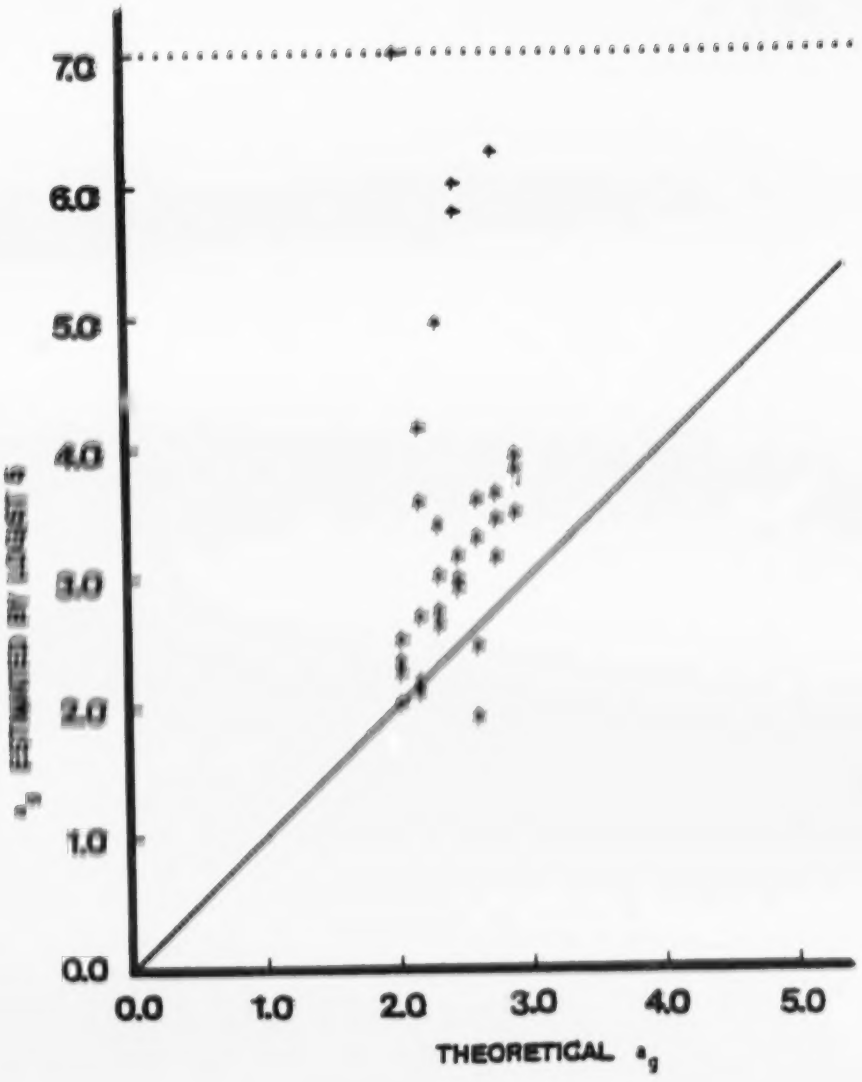

FIGURE 4-6

Estimated Discrimination Parameter Obtained by LOGIST 5 Plotted against the True Discrimination Parameter a_g for Each Item of the Thirty-Five Item Test (●). Case 2, 2,000 Subject Case.

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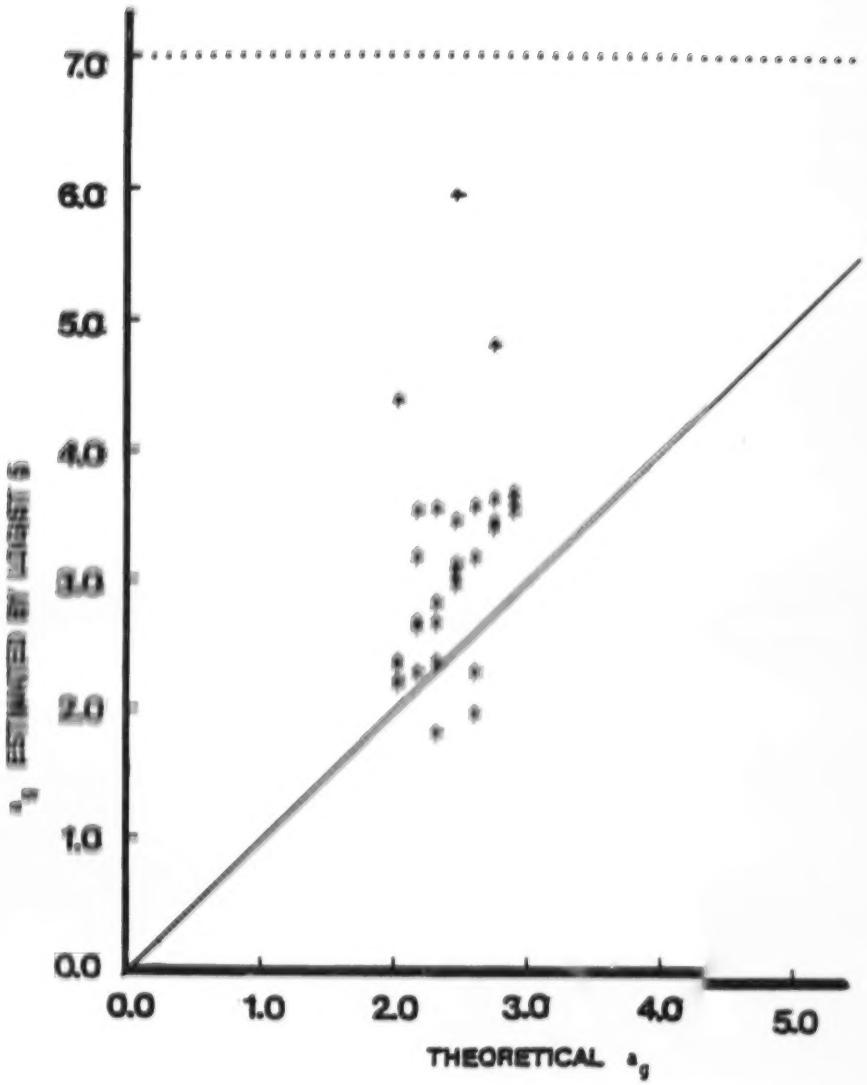

FIGURE 4-6 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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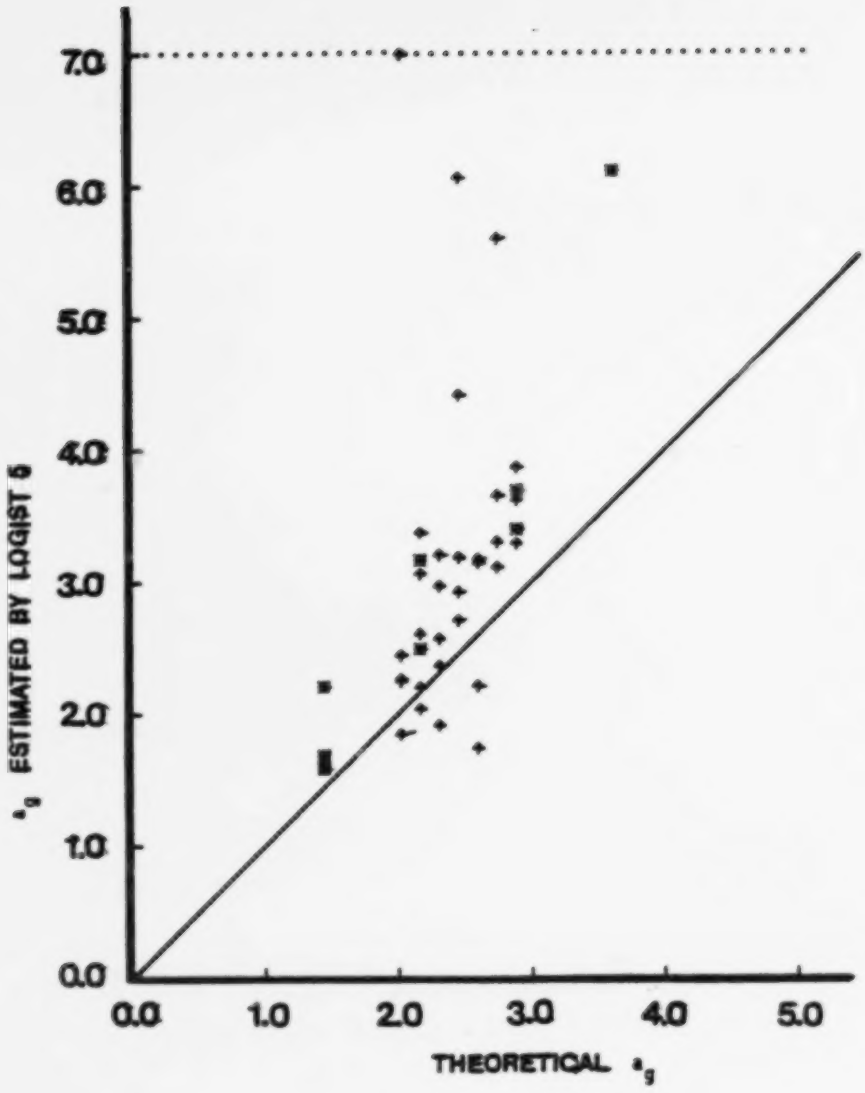

FIGURE 4-7

Estimated Discrimination Parameter Obtained by LOGIST 5 Plotted against the True Discrimination Parameter a_g for Each Item of the Ten Item Test (■) and of the Thirty-Five Item Test (◆). Case 3, 2,000 Subject Case.

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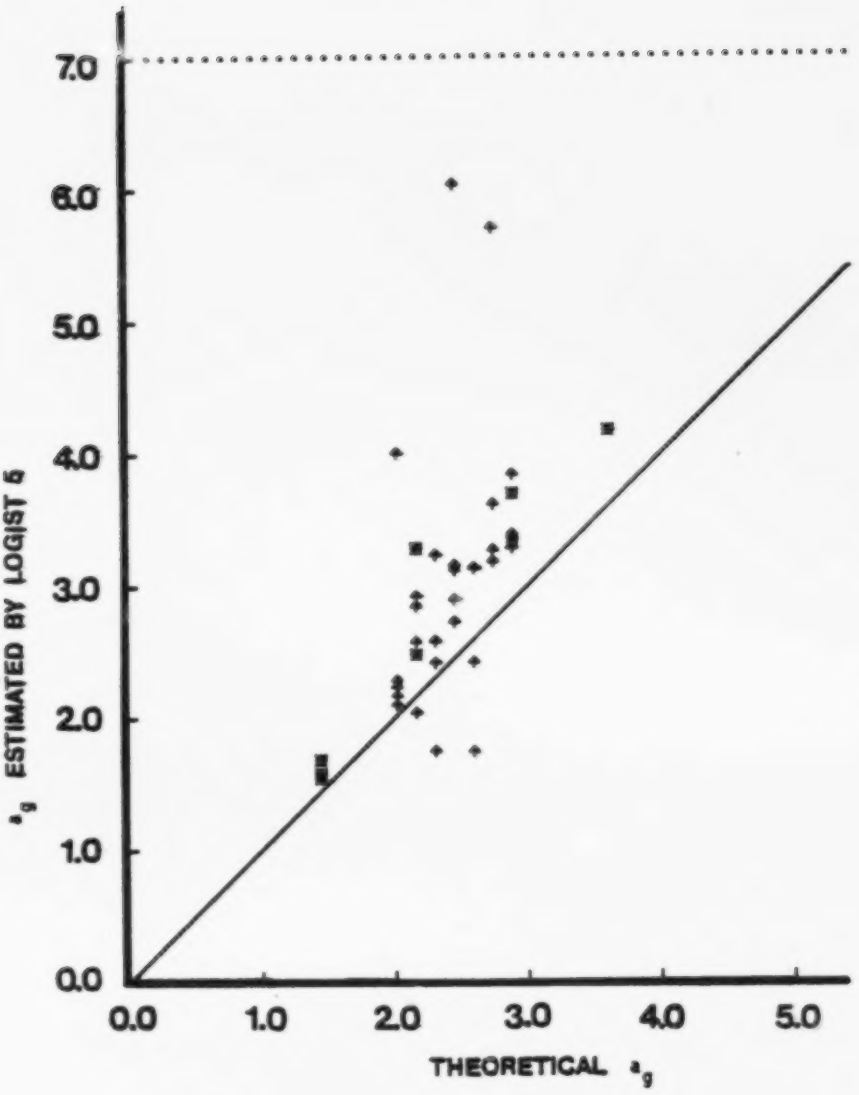

FIGURE 4-7 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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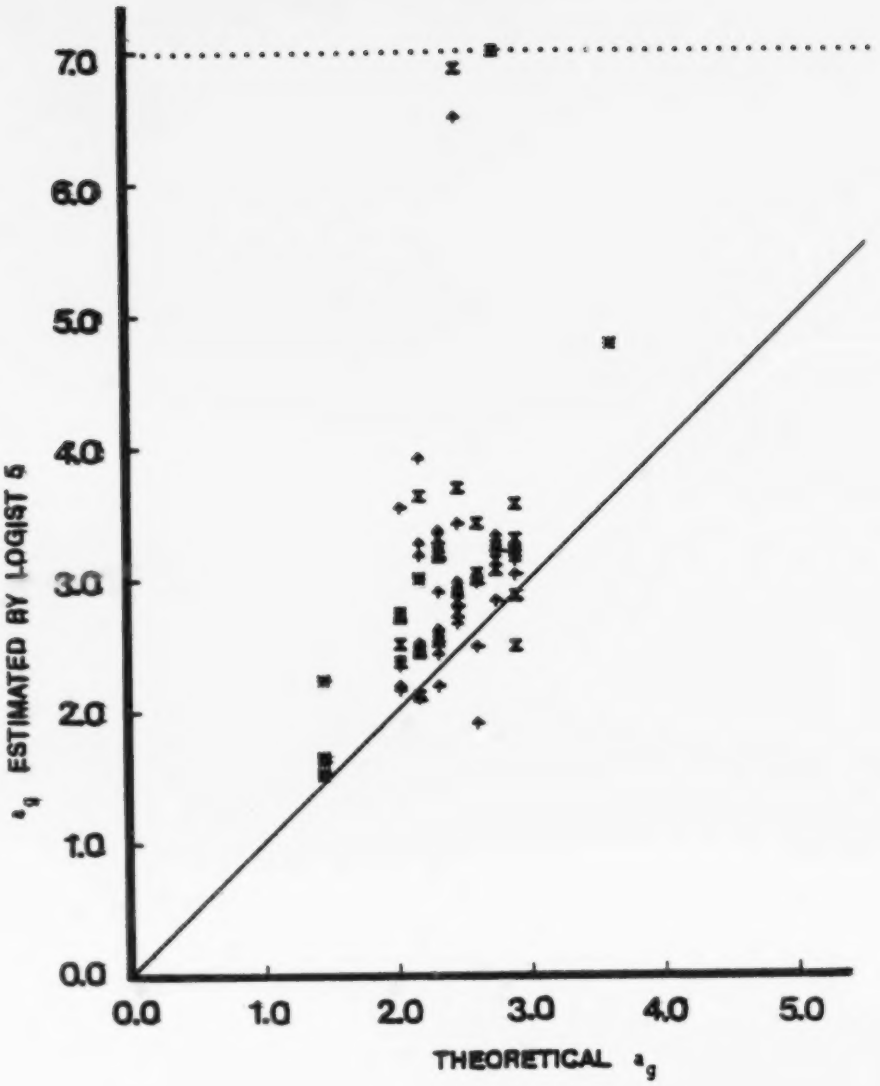

FIGURE 4-8

Estimated Discrimination Parameter Obtained by LOGIST 5 Plotted against the True Discrimination Parameter a_g for Each Item of the Ten Item Test (■) and of the Thirty-Five Item Test (+) and Each of the Additional Thirty-Five Items (×) for Case 4, 2000 Subject Case.

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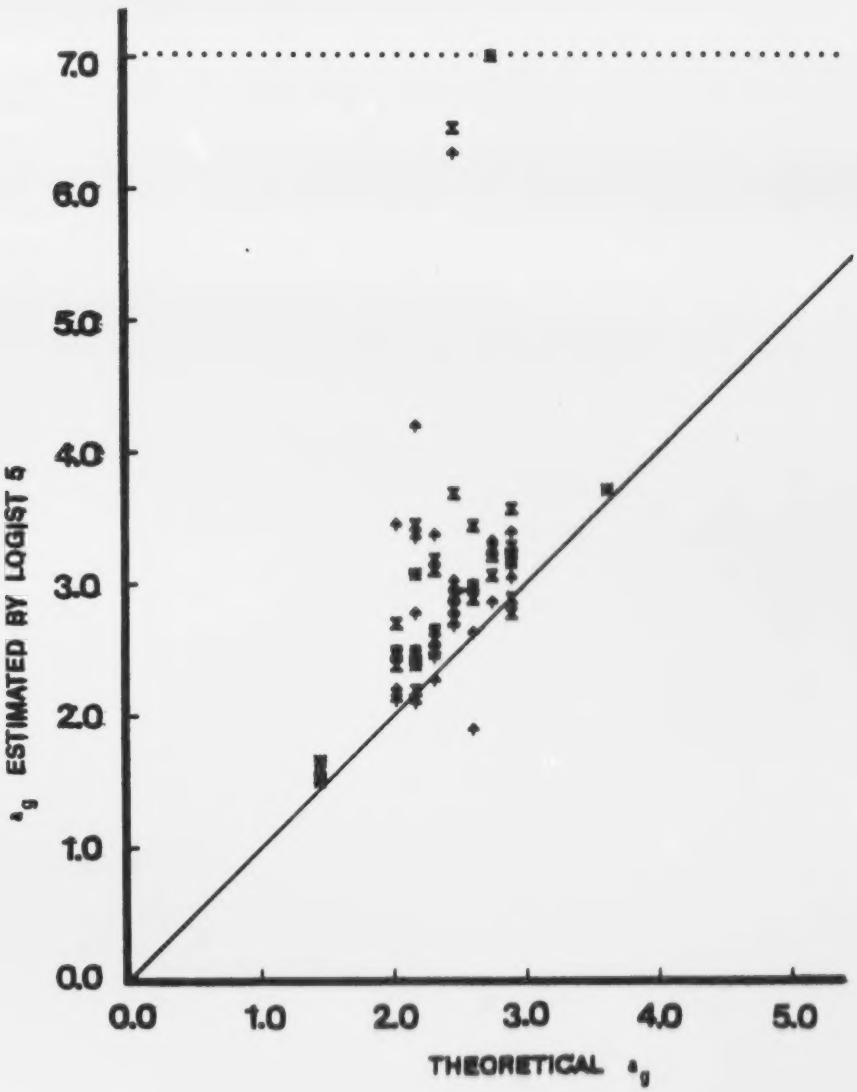

FIGURE 4-8 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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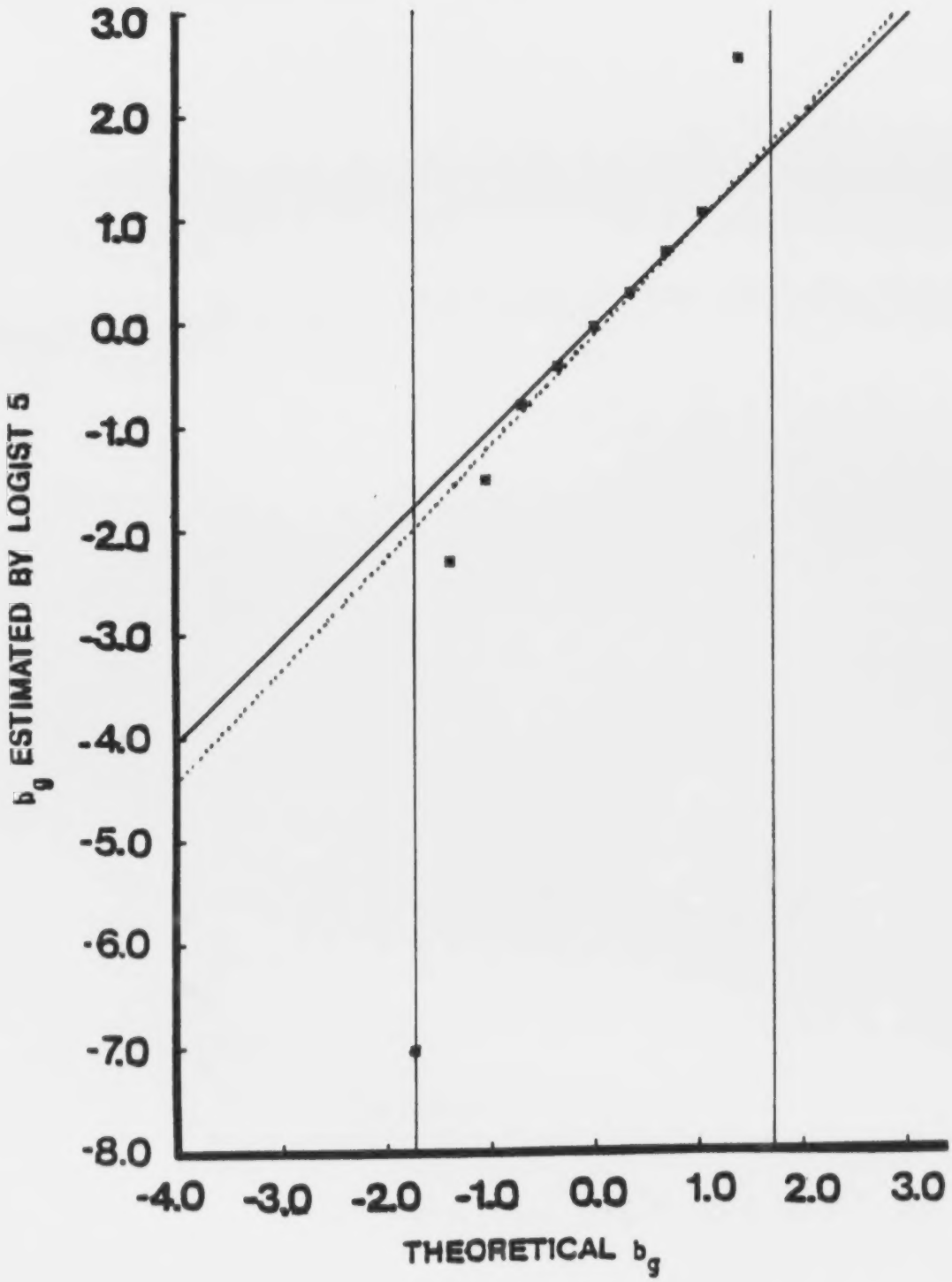

FIGURE 4-9

Estimated Difficulty Parameter Obtained by LOGIST 5 Plotted against the True Difficulty Parameter b_g for Each Item of the Ten Item Test (■). Case 1, 500 Subject Case.
(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

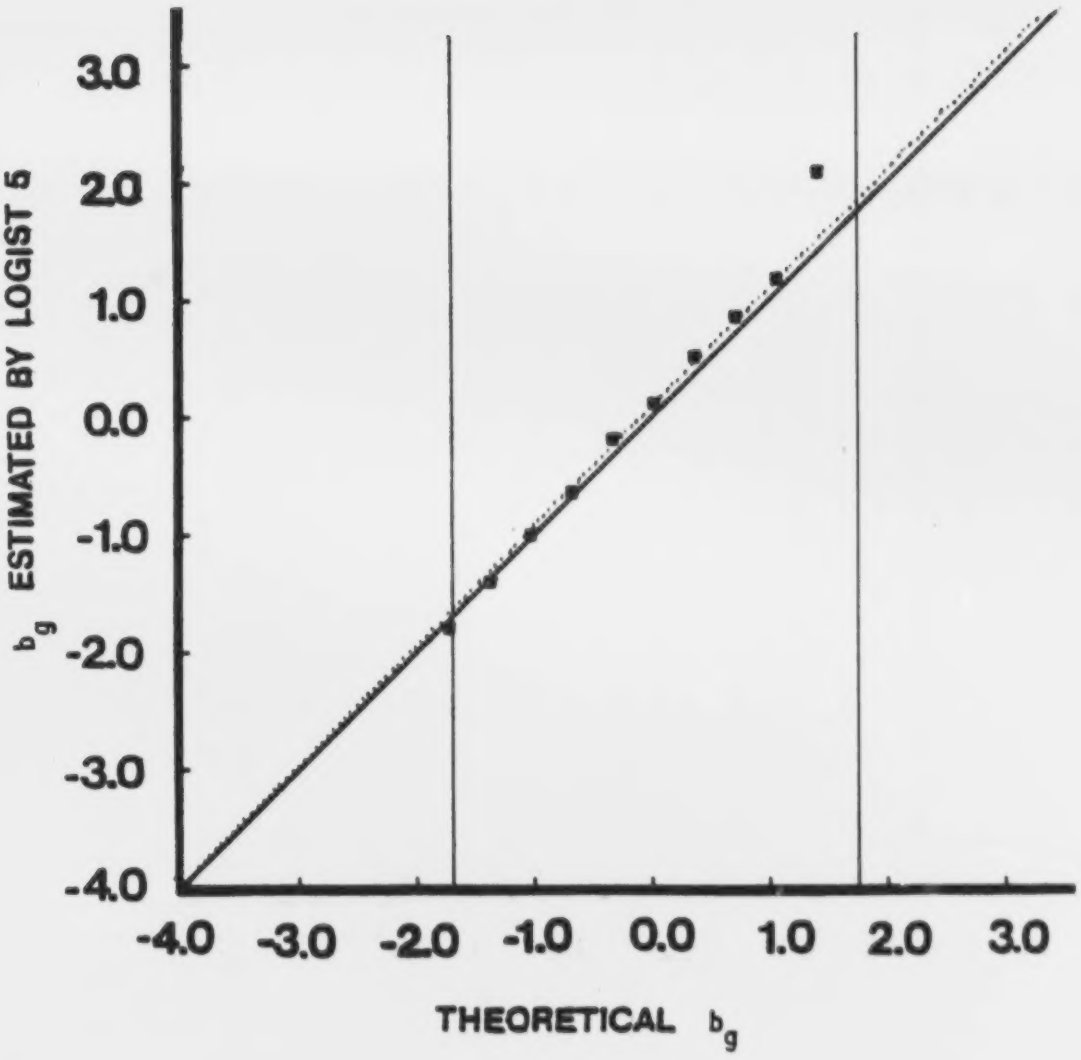

FIGURE 4-9 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.
(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

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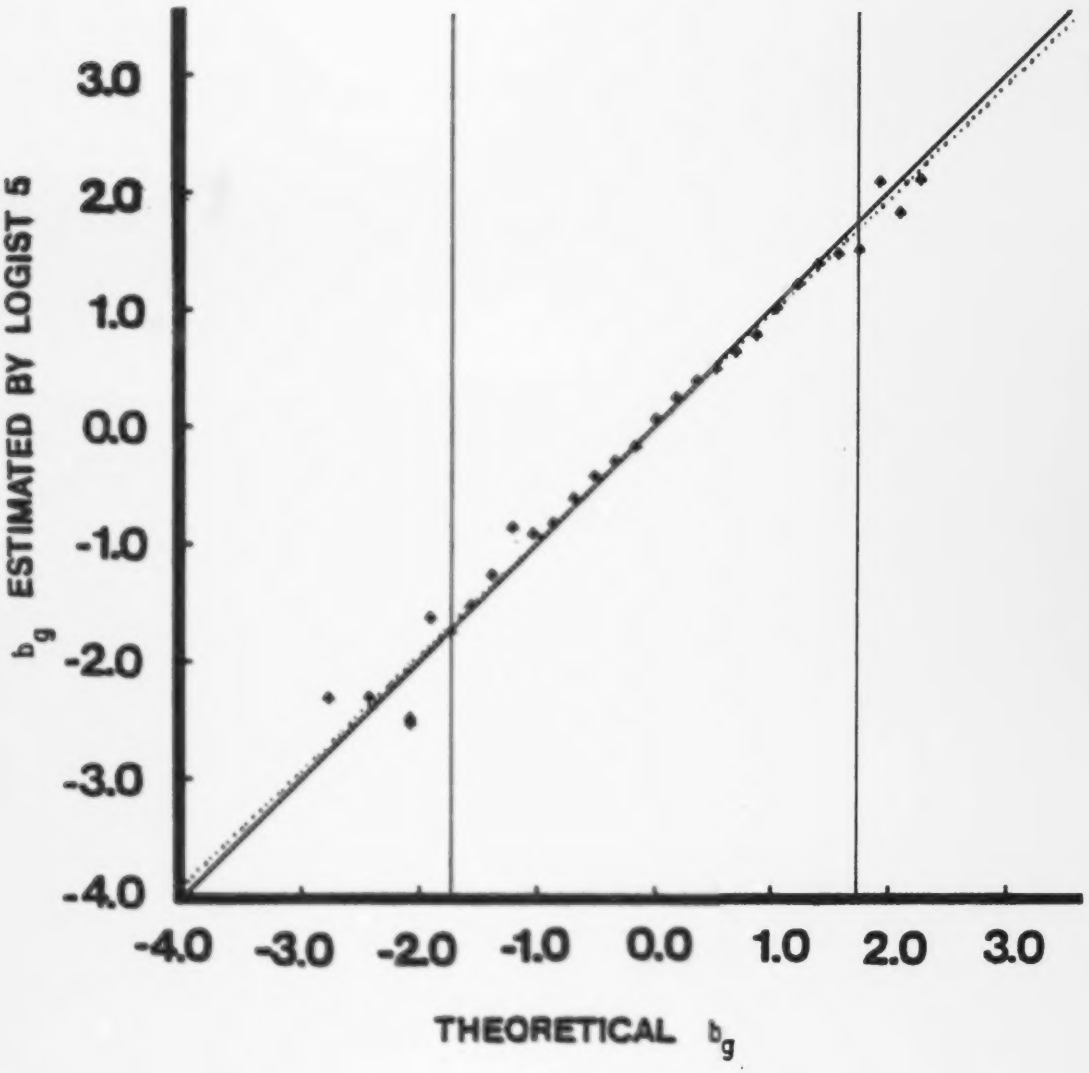

FIGURE 4-10

Estimated Difficulty Parameter Obtained by LOGIST 5 Plotted against the True Difficulty Parameter b_g for Each Item of the Thirty-Five Item Test (◆).
Case 2, 500 Subject Case.
(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

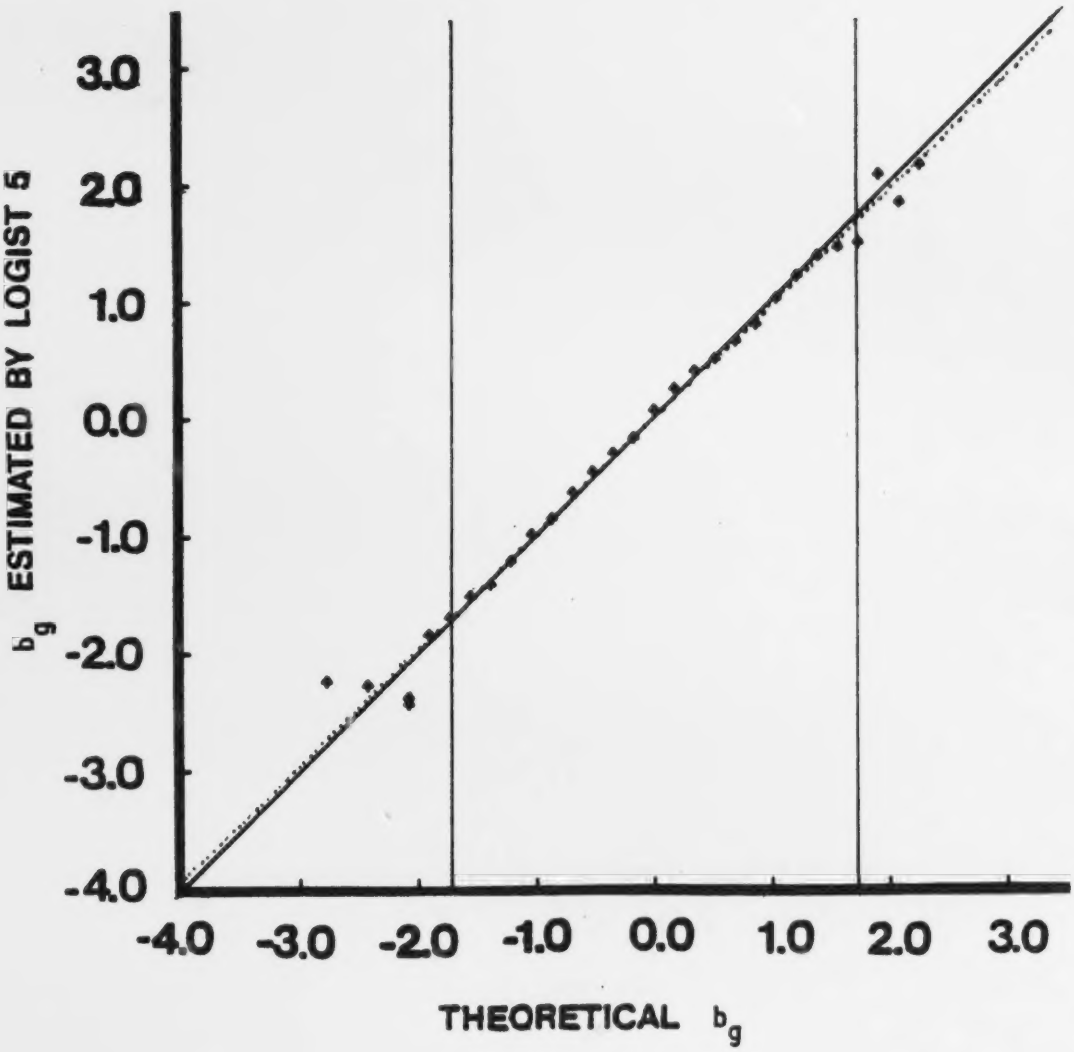

FIGURE 4-10 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.
(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

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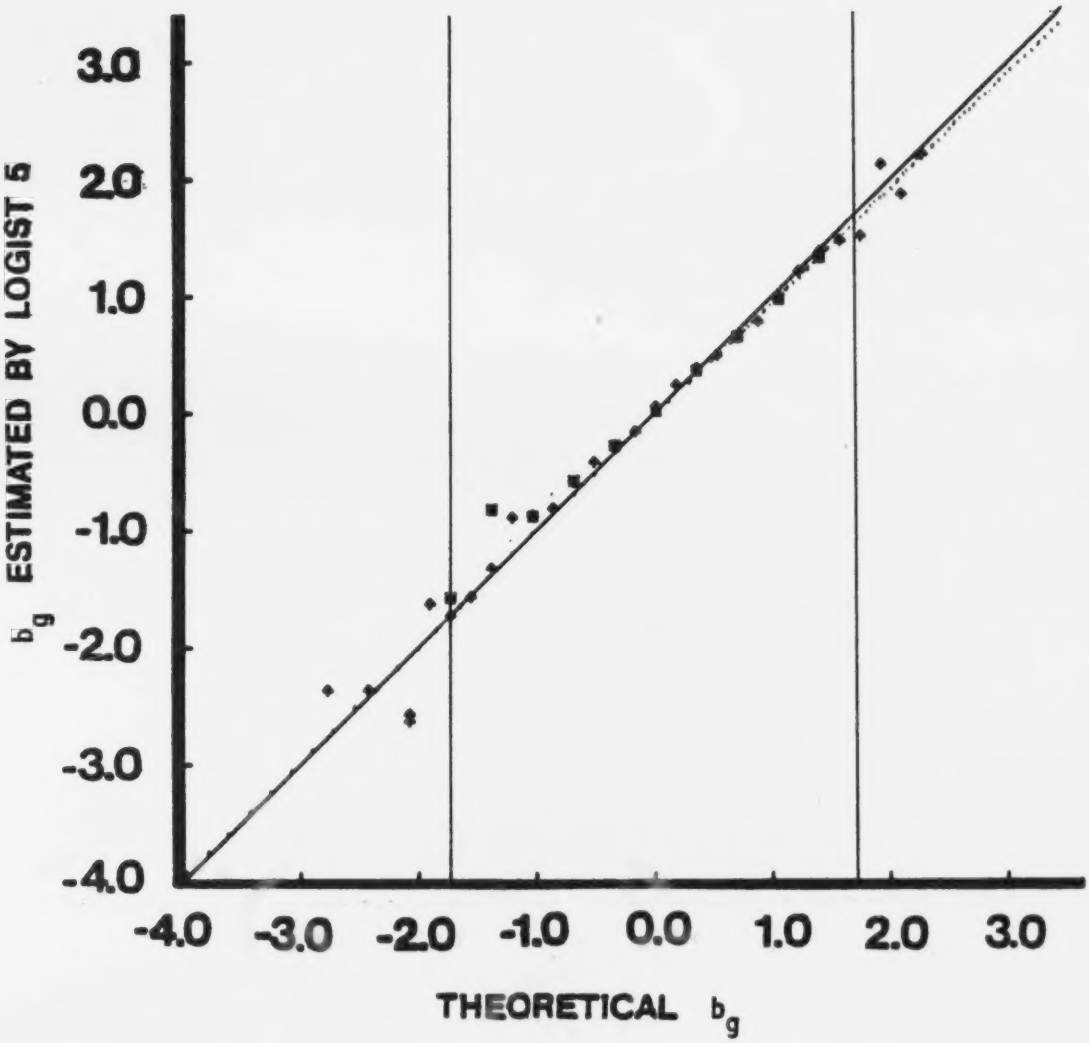

FIGURE 4-11

Estimated Difficulty Parameter Obtained by LOGIST 5 Plotted against the True Difficulty Parameter b_g for Each Item of the Ten Item Test (■) and of the Thirty-Five Item Test (◆). Case 3, 500 Subject Case.
(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

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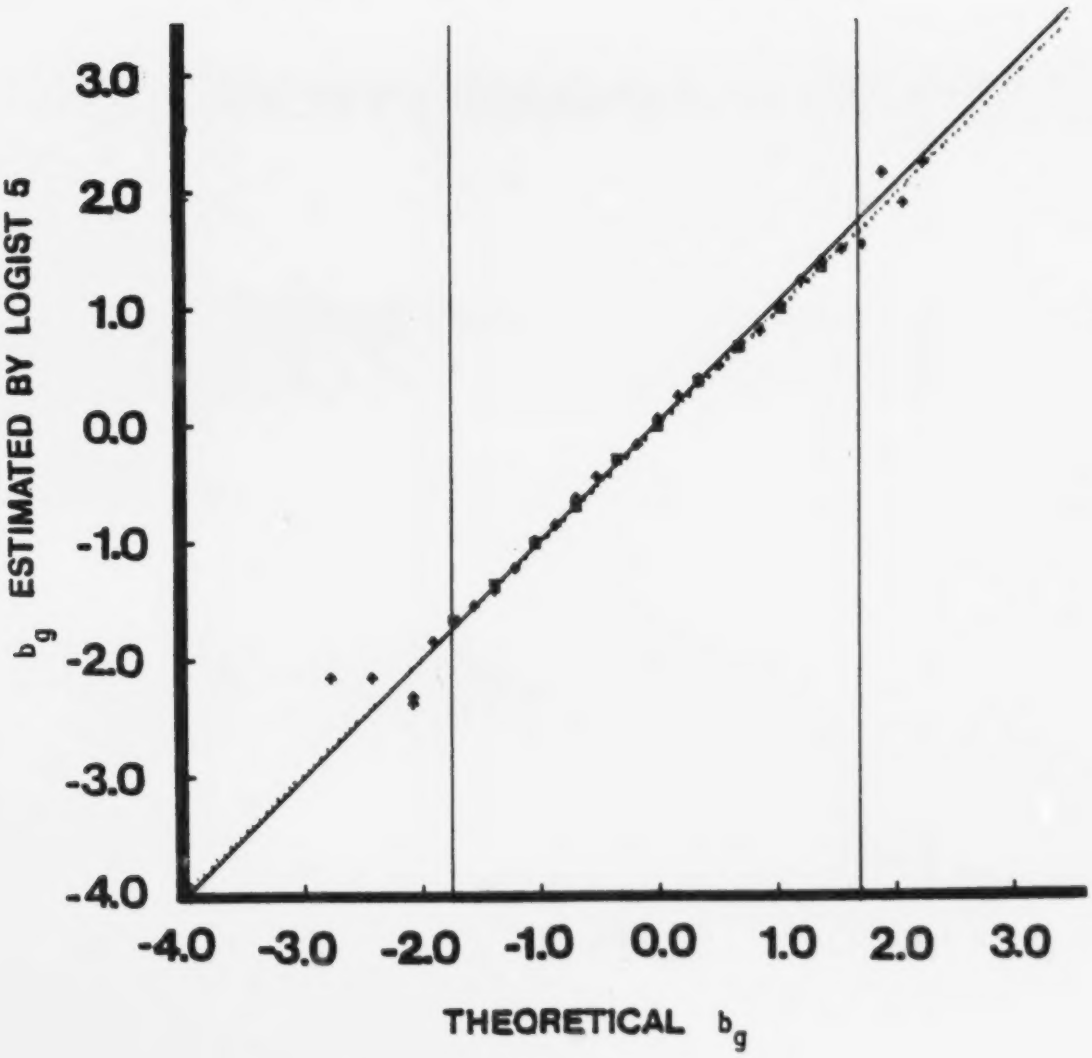

FIGURE 4-11 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.
(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

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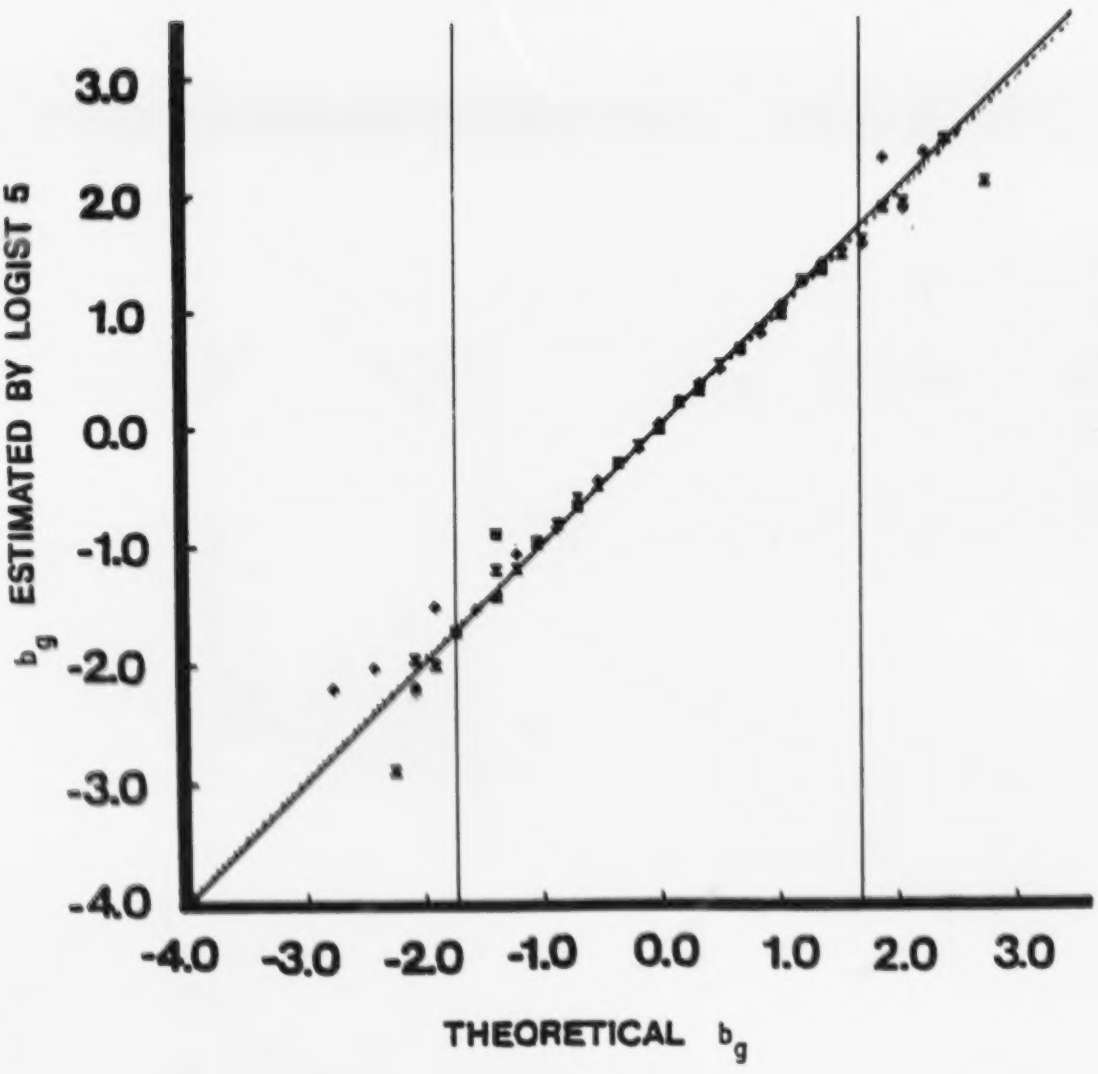

FIGURE 4-12

Estimated Difficulty Parameter Obtained by LOGIST 5 Plotted against the True Difficulty Parameter b_g for Each Item of the Ten Item Test (■) and of the Thirty-Five Item Test (●) and Each of the Additional Thirty-Five Items (■). Case 4, 500 Subject Case.
(Linear Regression of $\hat{b}_g$ on b_g is Plotted by Dots for Reference.)

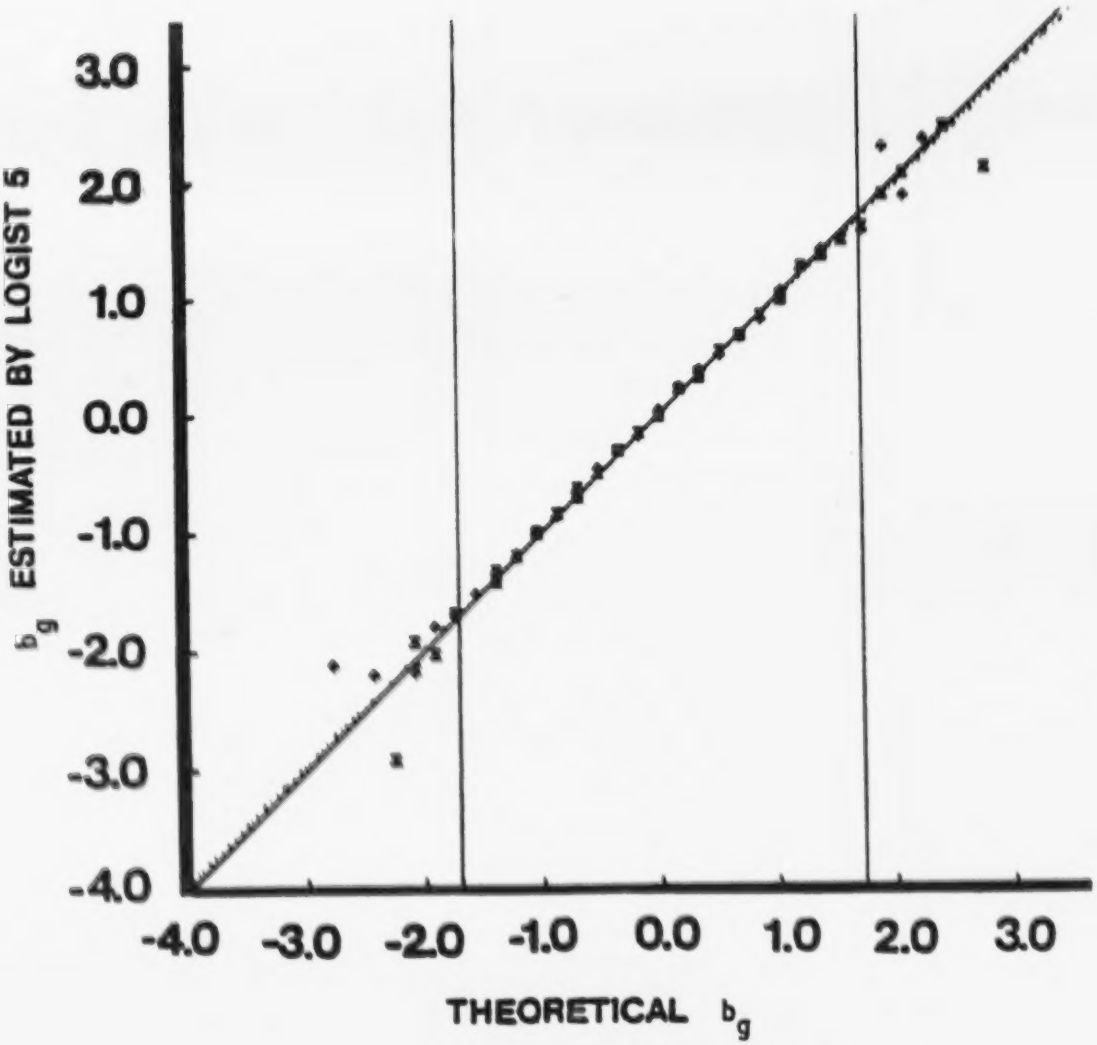

FIGURE 4-12 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.
(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

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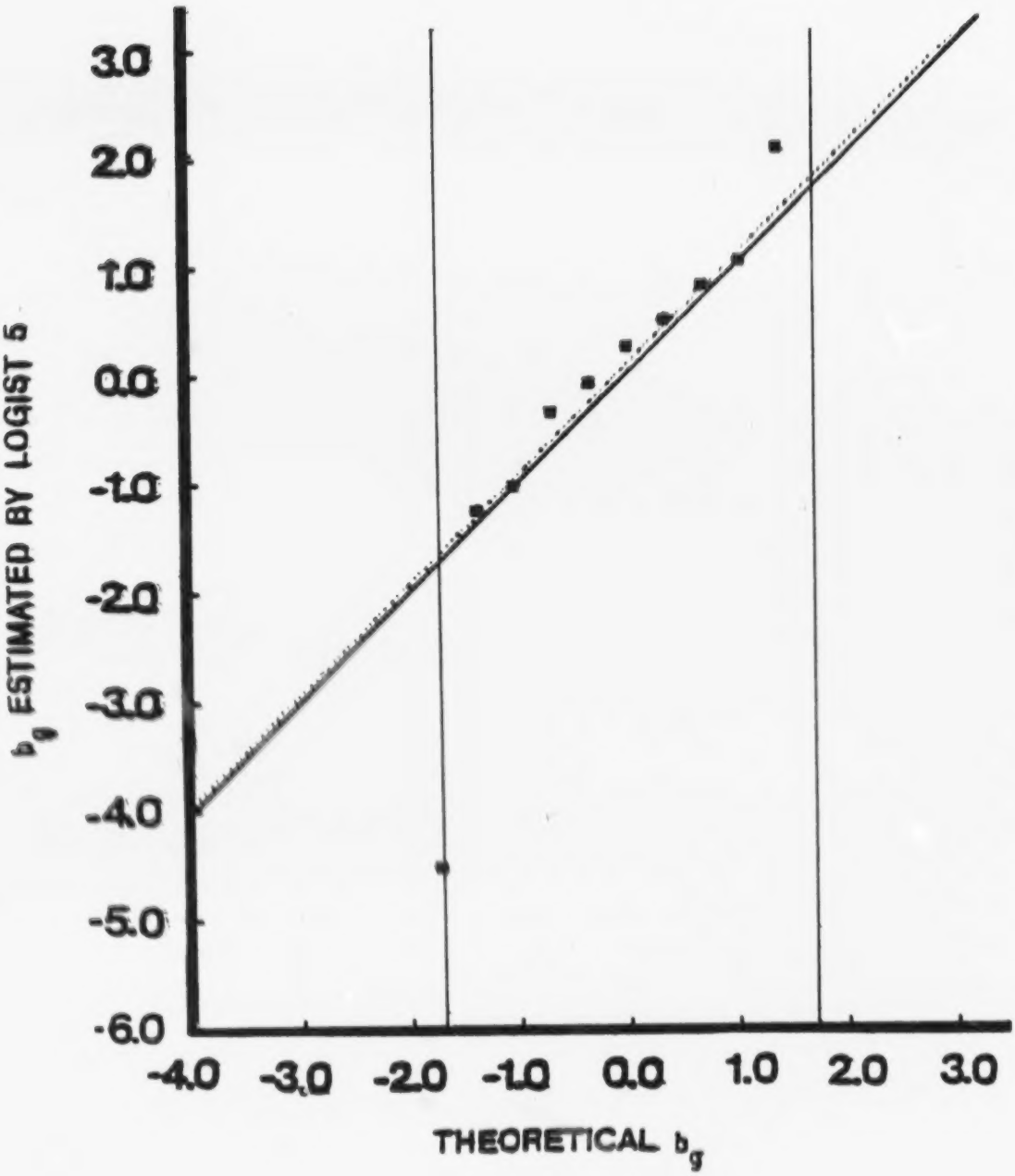

FIGURE 4-13

Estimated Difficulty Parameter Obtained by LOGIST 5 Plotted against the True Difficulty Parameter (b_g) for Each Item of the Ten Item Test (■). Case 1: 2,000 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ is Plotted by Dots for Reference.)

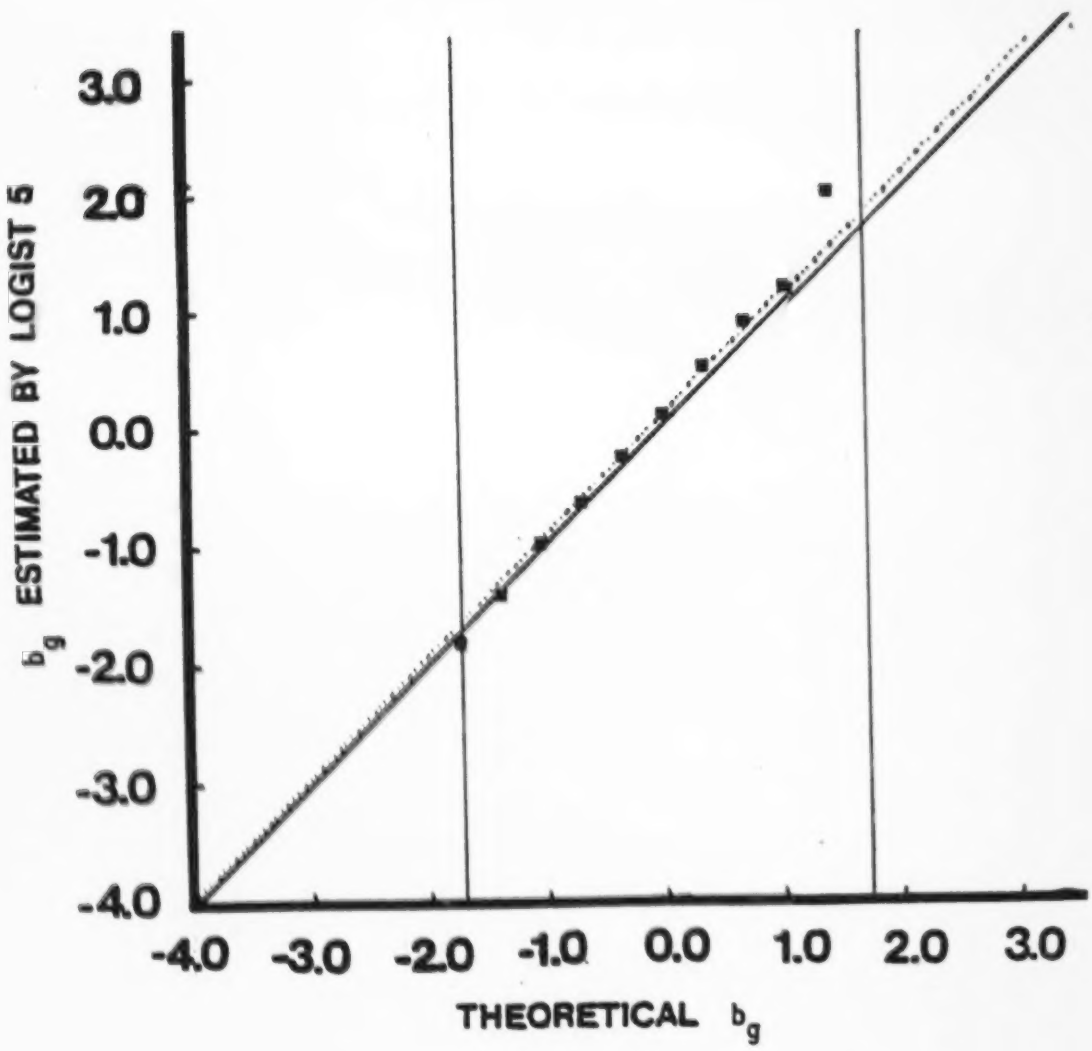

FIGURE 4-13 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.
(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

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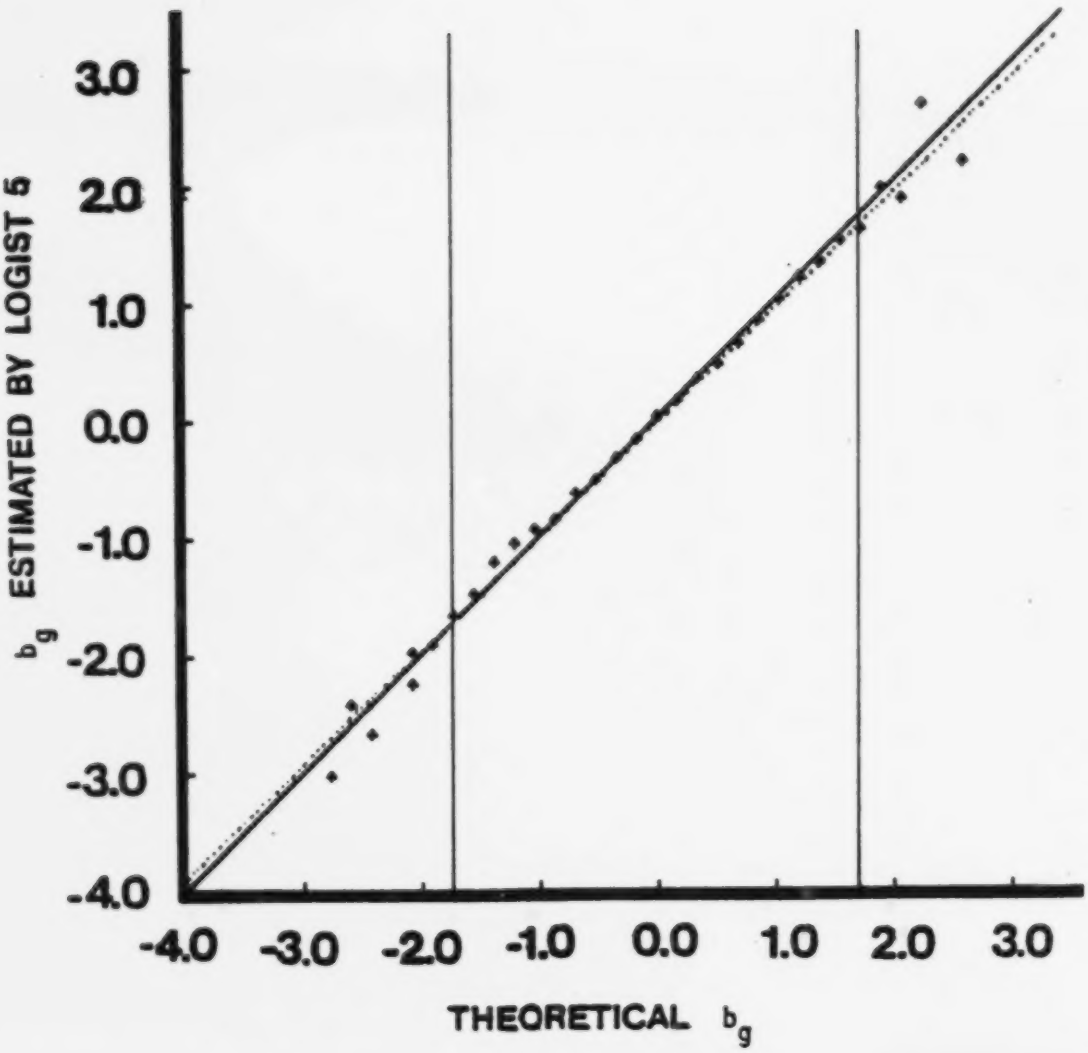

FIGURE 4-14

Estimated Difficulty Parameter Obtained by LOGIST 5 Plotted against the True Difficulty Parameter b_g for Each Item of the Thirty-Five Item Test (◆). Case 2, 2,000 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

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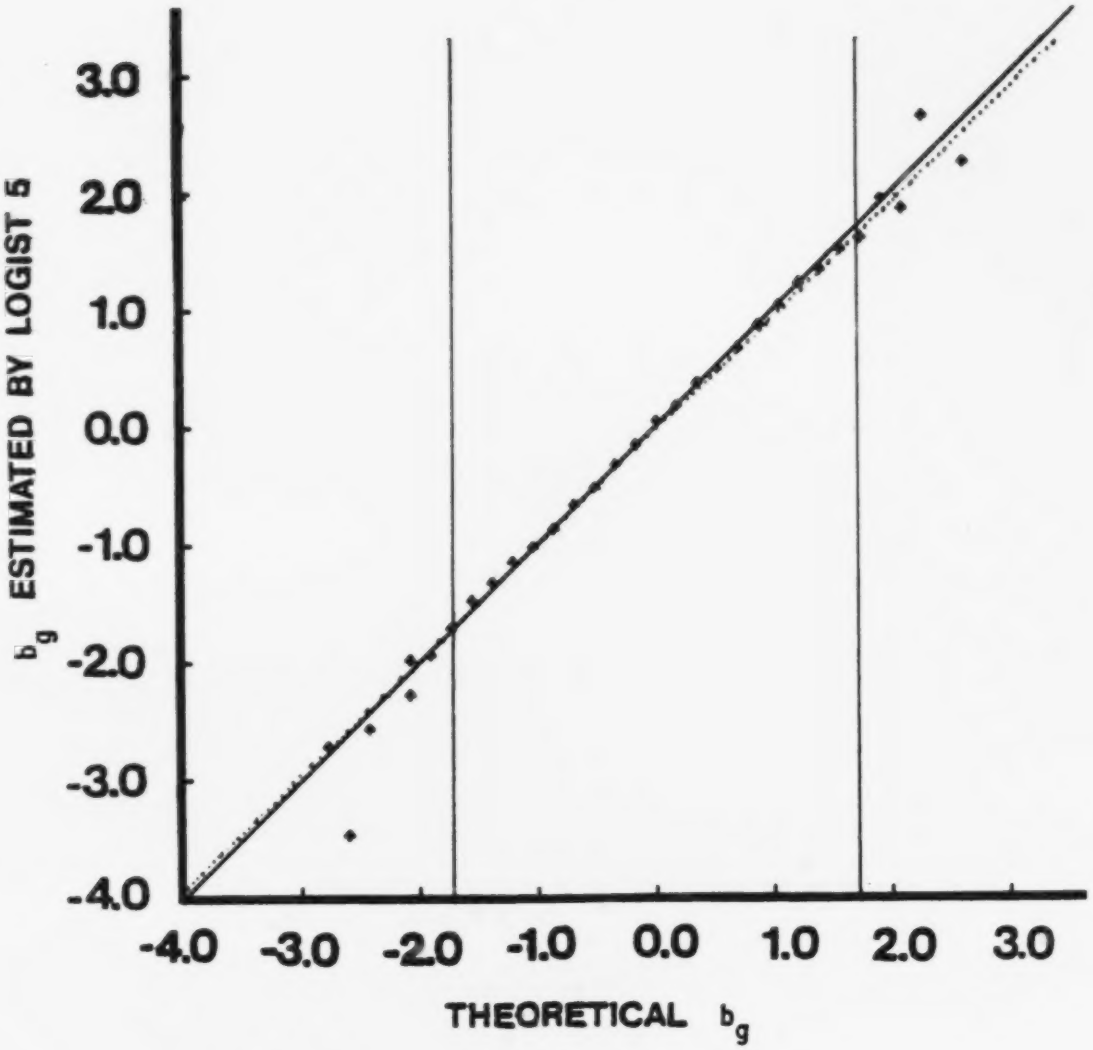

FIGURE 4-14 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.
(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

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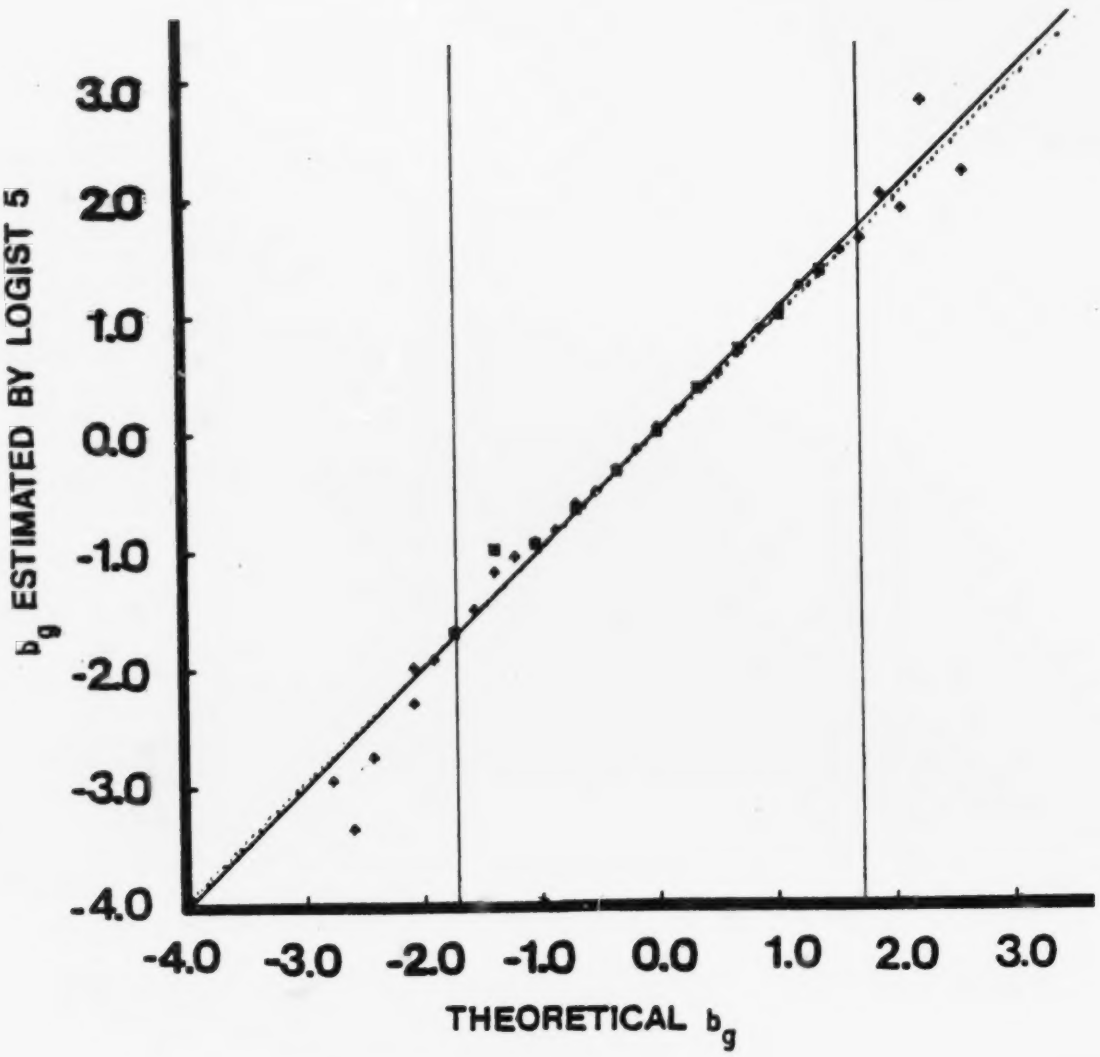

FIGURE 4-15

Estimated Difficulty Parameter Obtained by LOGIST 5 Plotted against the True Difficulty Parameter b_g for Each Item of the Ten Item Test (■) and of the Thirty-Five Item Test (◆). Case 3, 2,000 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

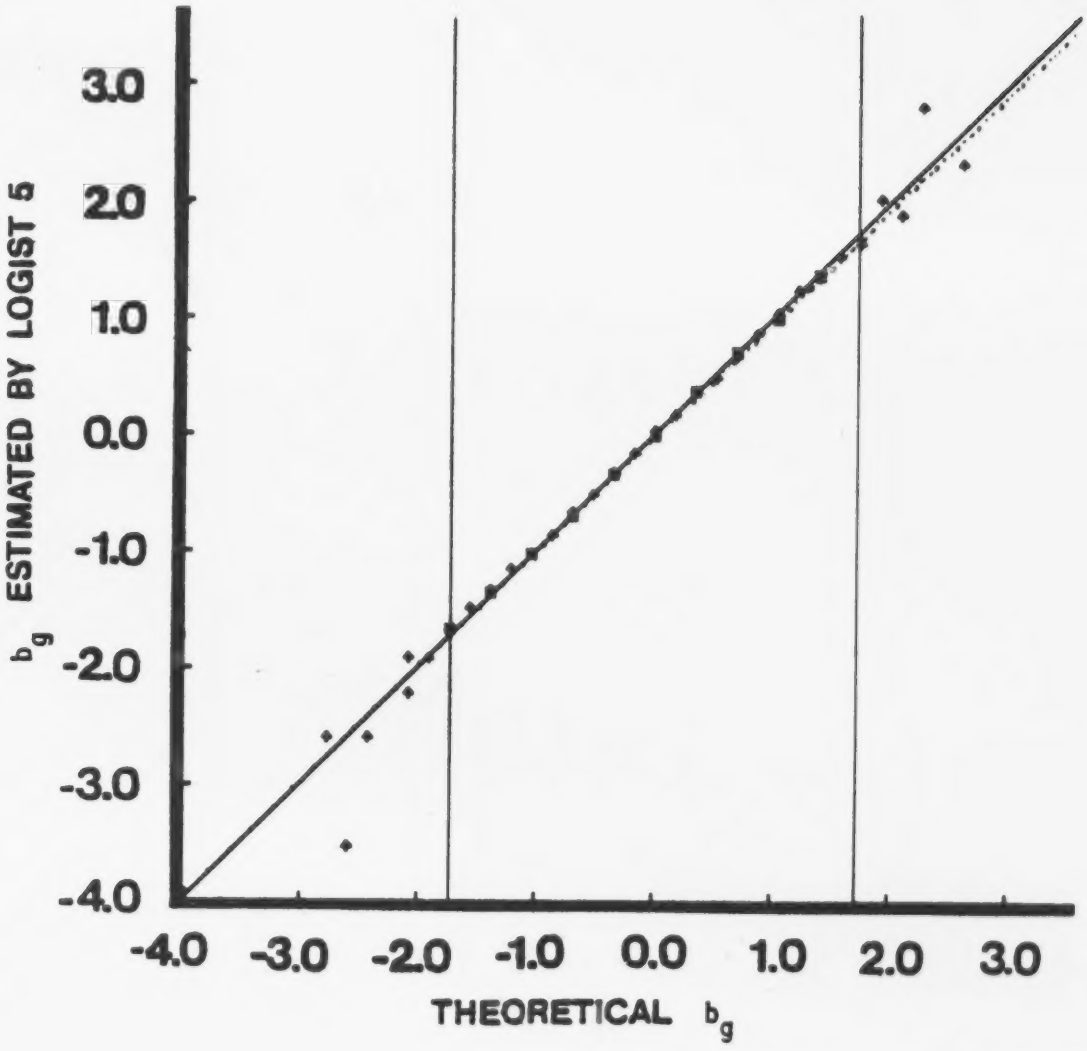

FIGURE 4-15 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.
(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

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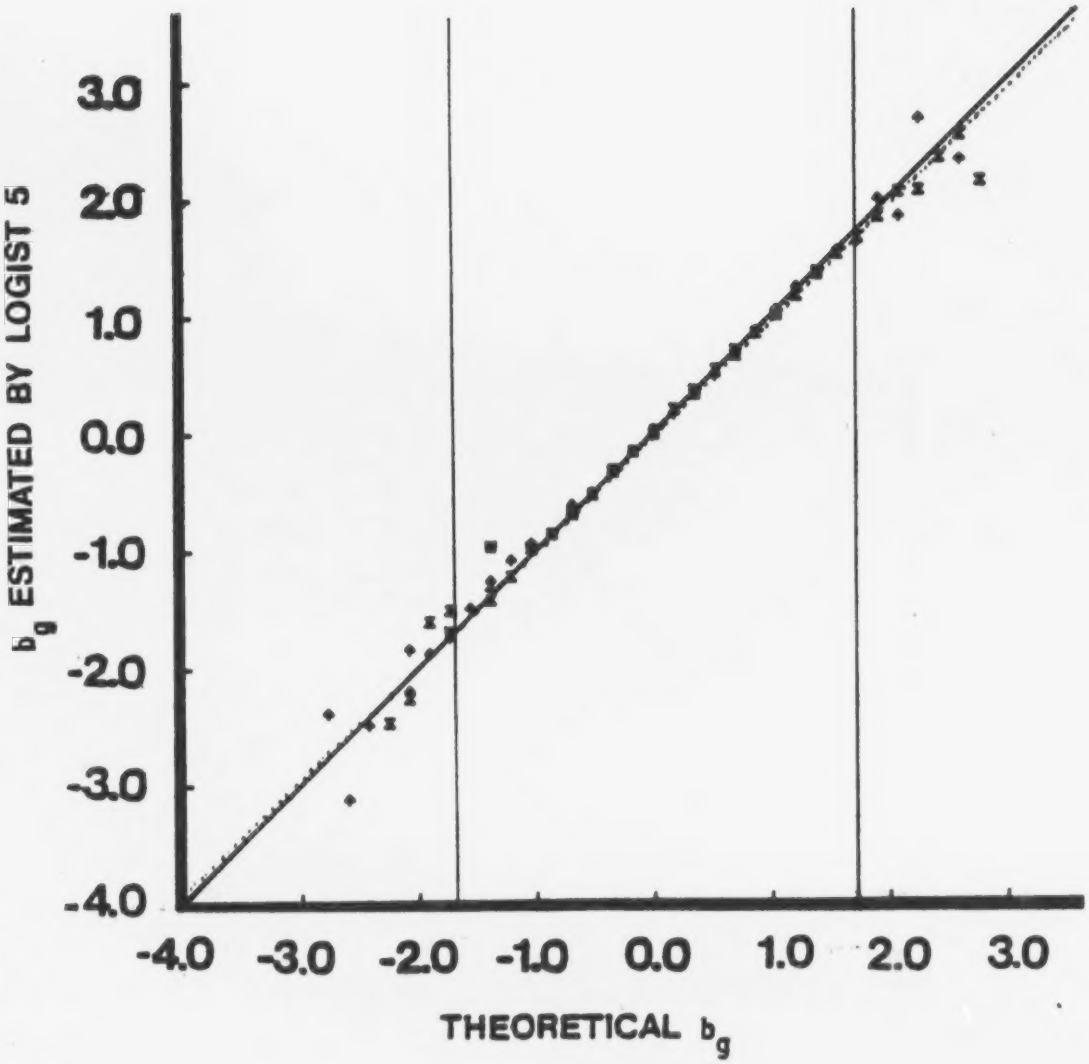

FIGURE 4-16

Estimated Difficulty Parameter Obtained by LOGIST 5 Plotted against the True Difficulty Parameter b_g for Each Item of the Ten Item Test (■) and of the Thirty-Five Item Test (•) and of Each of the Additional Thirty-Five Items(✖). (Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

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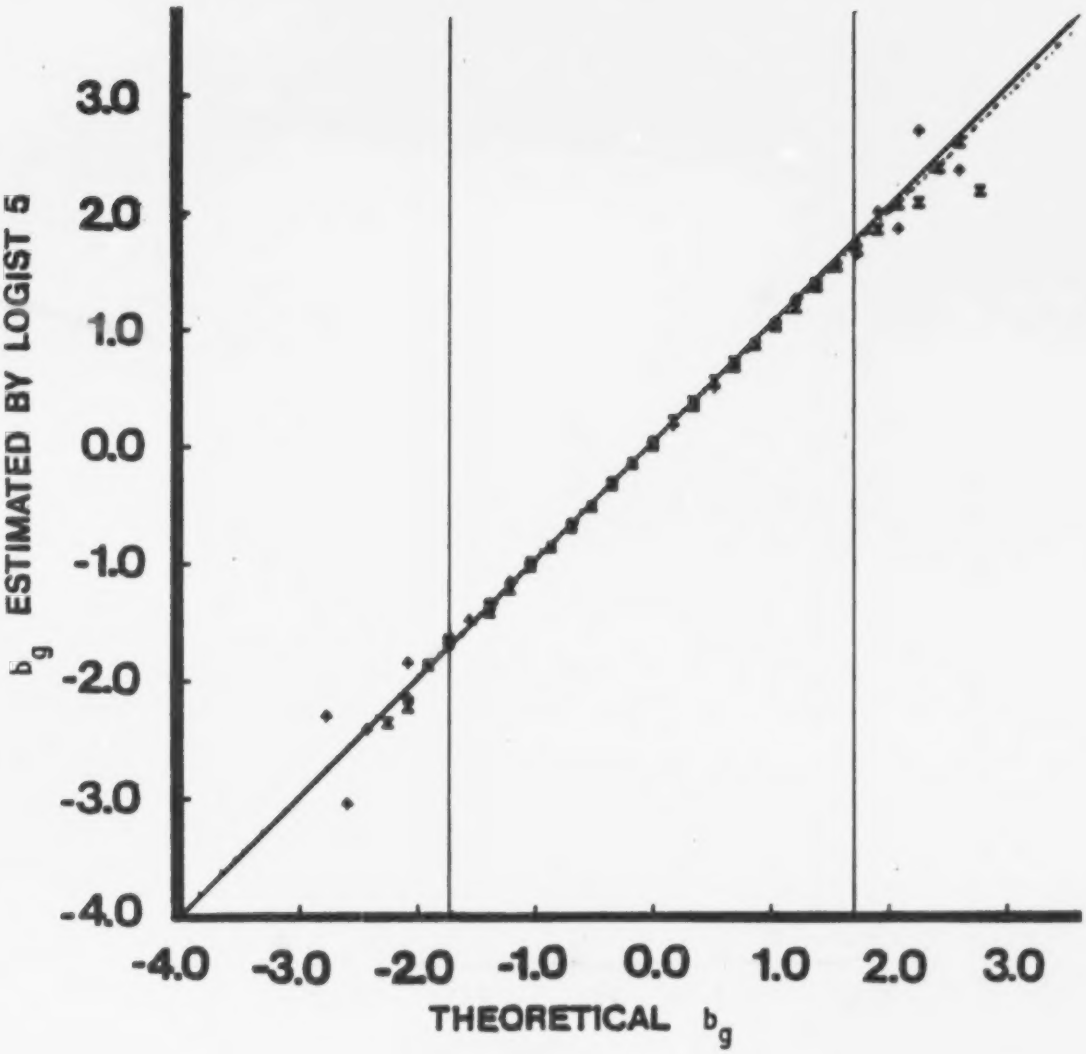

FIGURE 4-16 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.
(Linear Regression of $\hat{\theta}$ on θ Is Plotted by Dots for Reference.)

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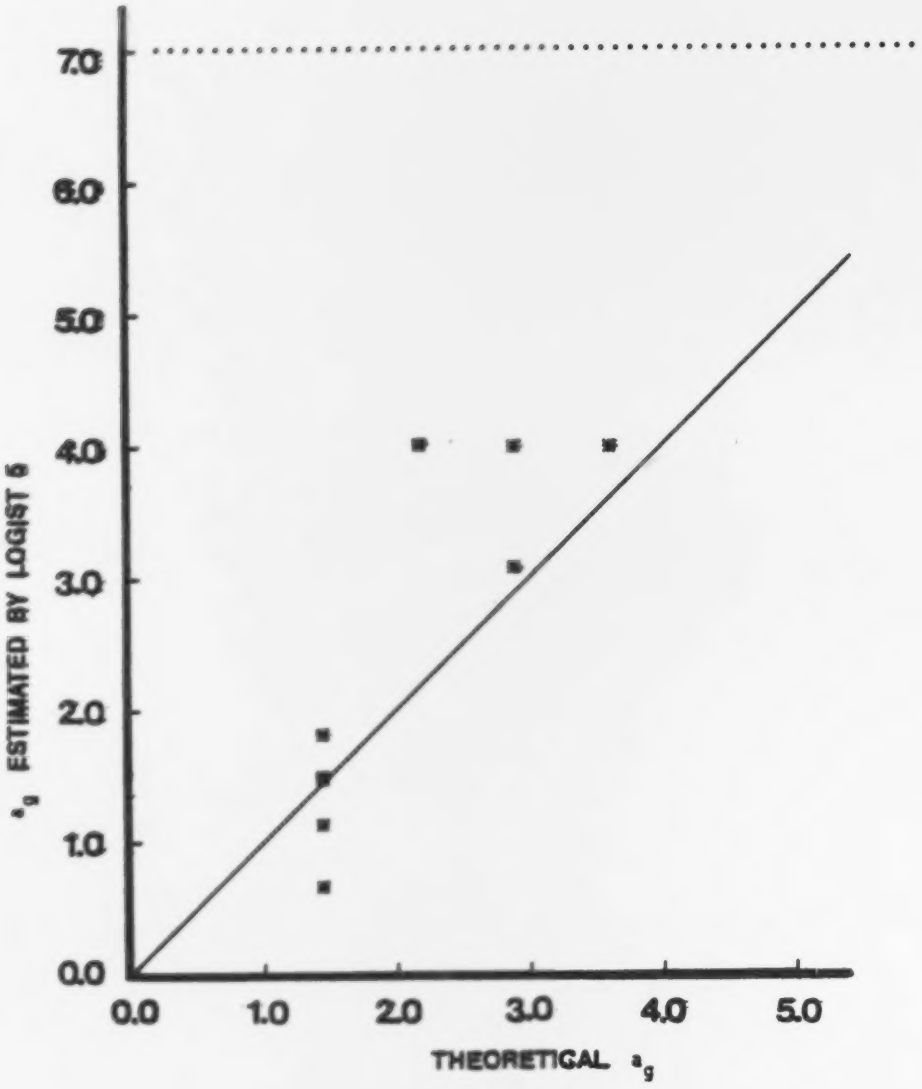

FIGURE 4-17

Reduced Scatter Diagram of the Theoretical and Estimated Item Discrimination Parameters Obtained by Excluding All Items Whose Theoretical Item Difficulty Parameters Are Outside the Interval $(-\sqrt{3}, \sqrt{3})$. Case 1, 500 Subject Case.

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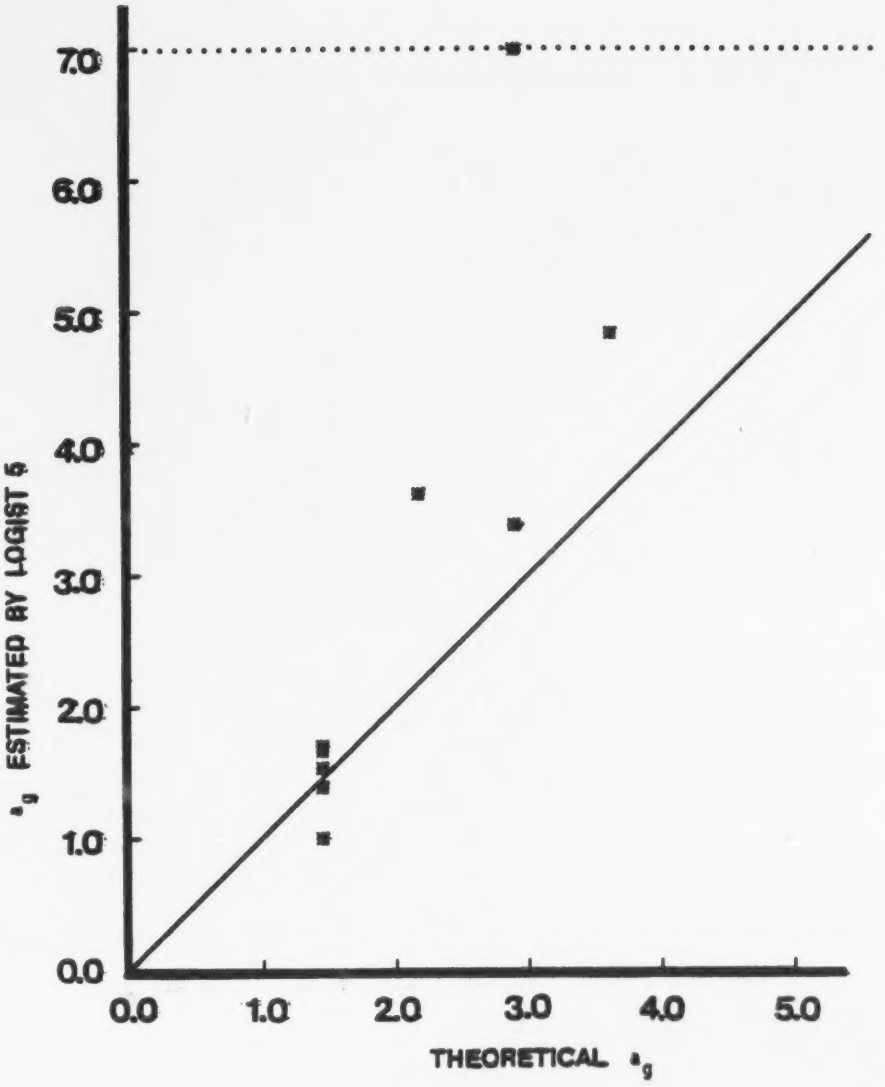

FIGURE 4-17 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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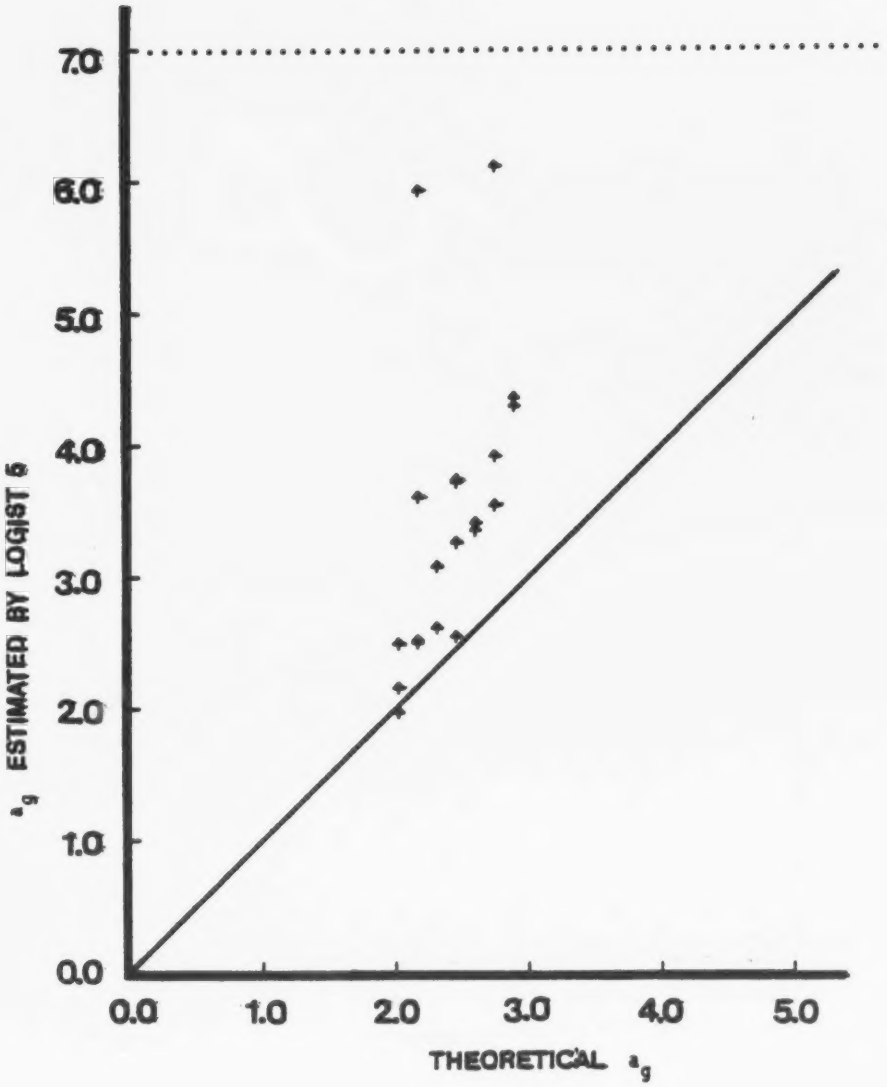

FIGURE 4-18

Reduced Scatter Diagram of the Theoretical and Estimated Item Discrimination Parameters Obtained by Excluding All Items Whose Theoretical Item Difficulty Parameters Are Outside the Interval $(-\sqrt{3}, \sqrt{3})$. Case 2, 500 Subject Case.

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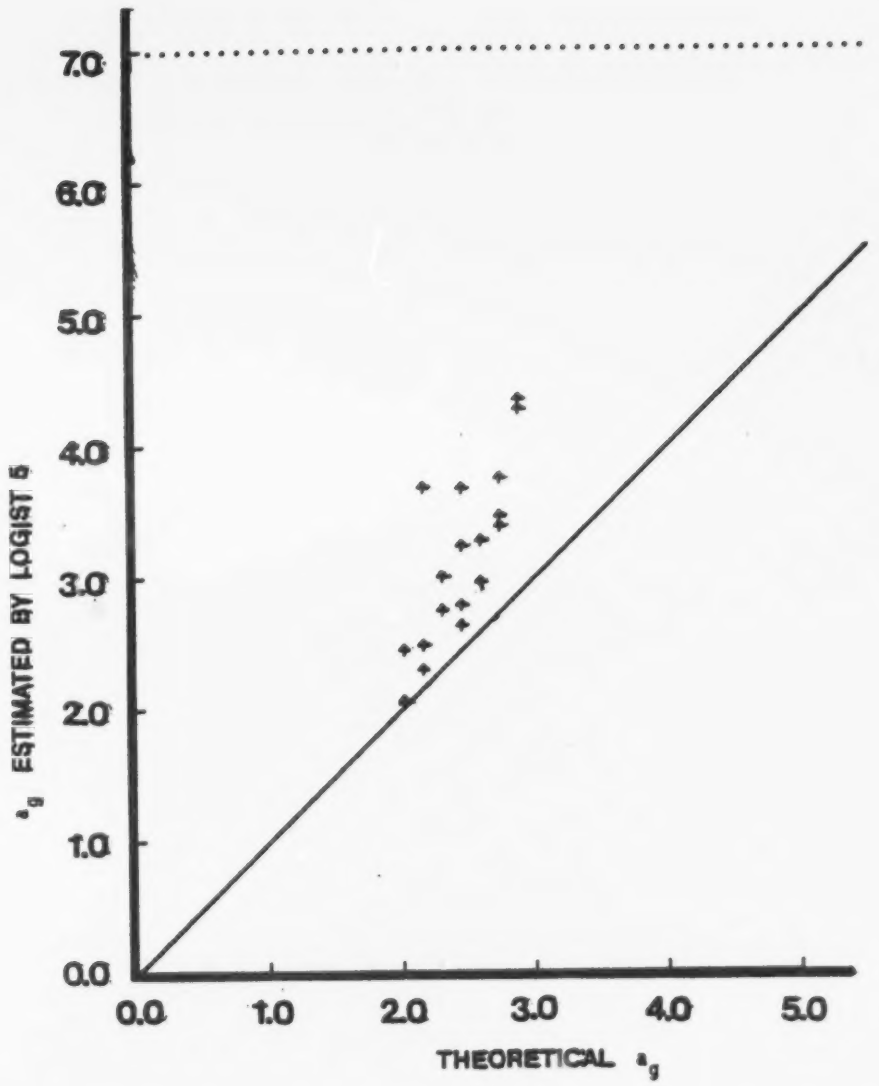

FIGURE 4-18 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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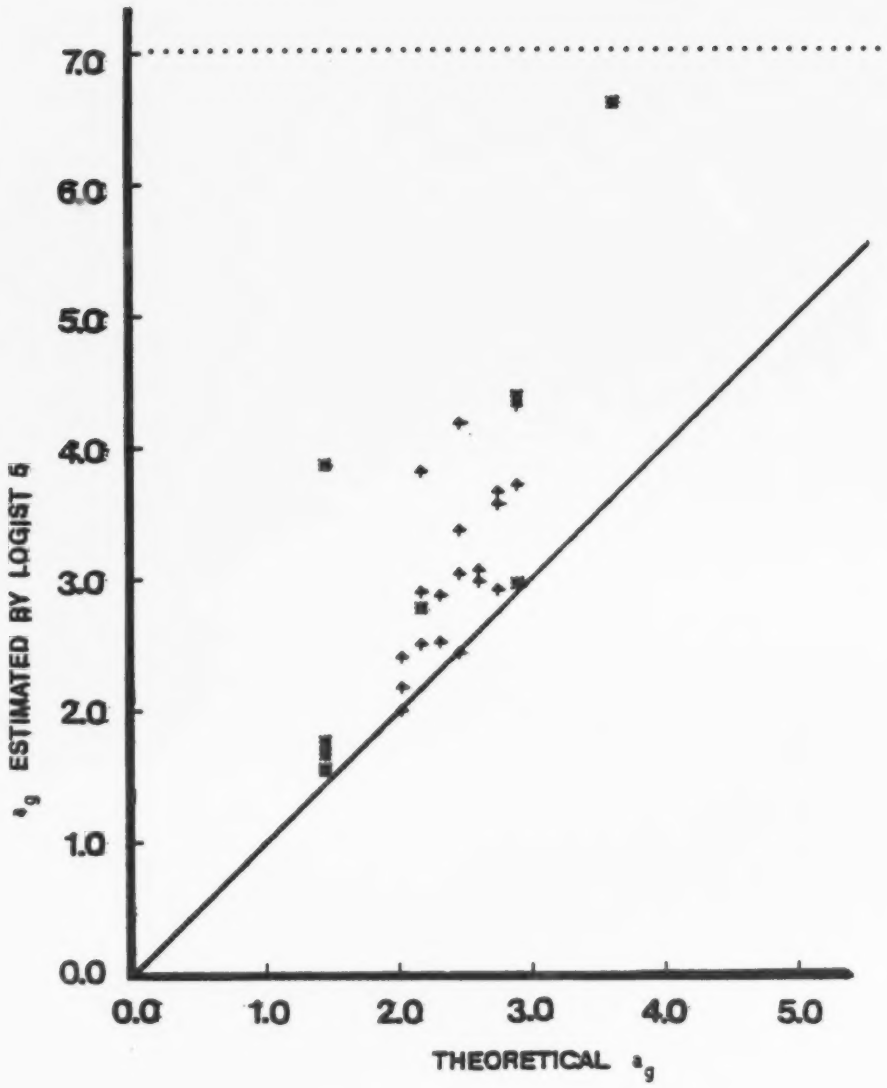

FIGURE 4-19

Reduced Scatter Diagram of the Theoretical and Estimated Item Discrimination Parameters Obtained by Excluding All Items Whose Theoretical Item Difficulty Parameters Are Outside the Interval $(-\sqrt{3}, \sqrt{3})$. Case 3, 500 Subject Case.

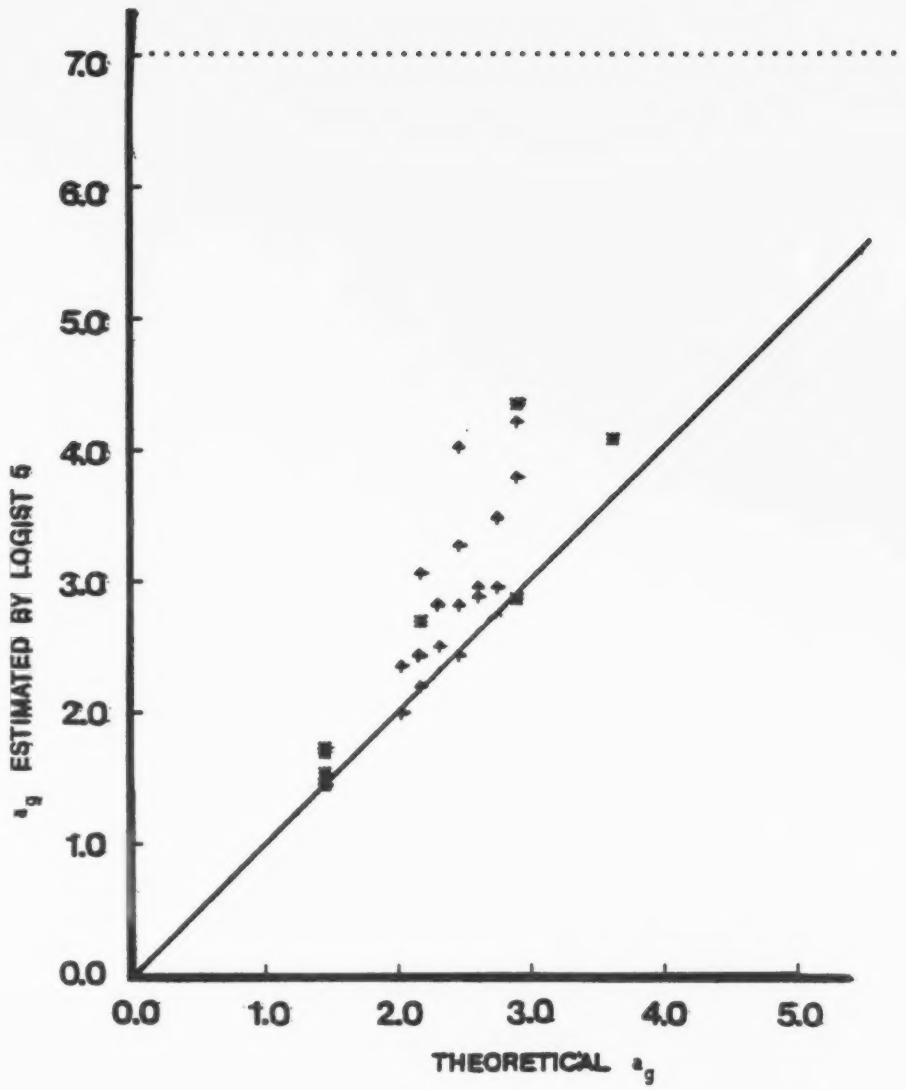

FIGURE 4-19 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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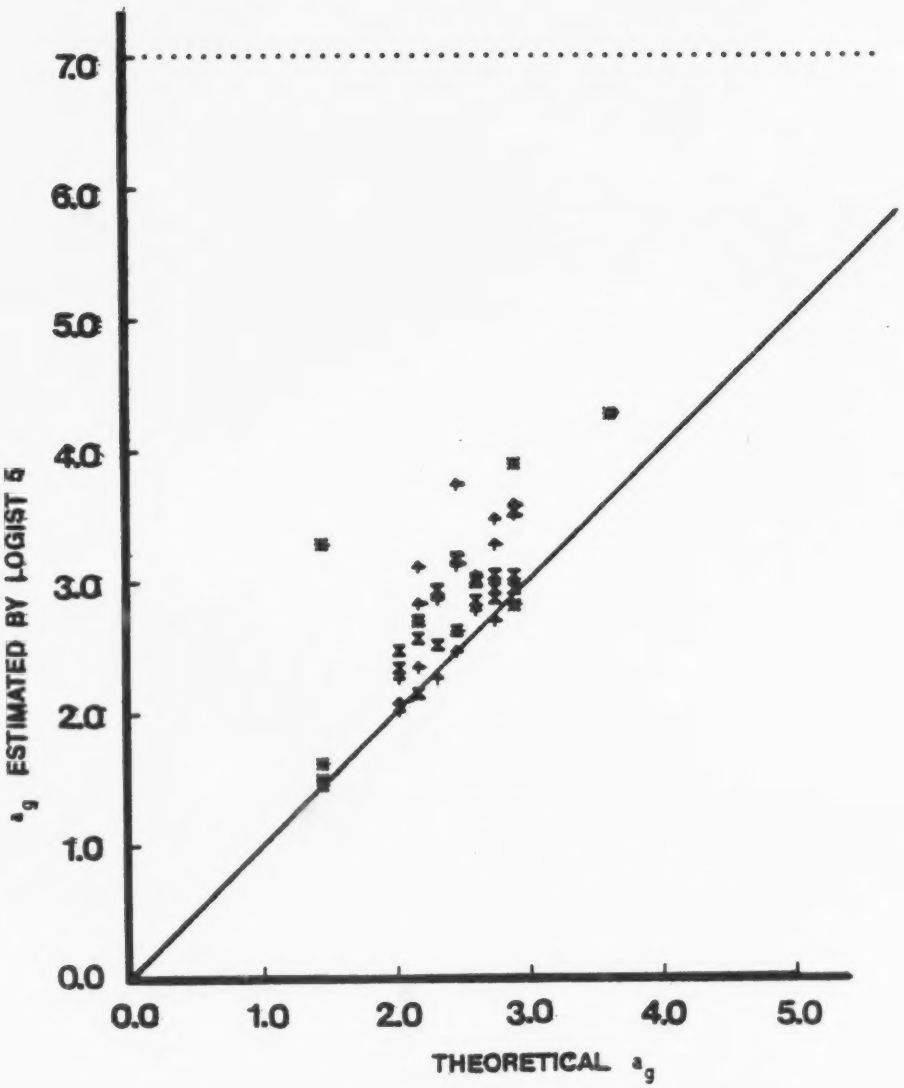

FIGURE 4-20

Reduced Scatter Diagram of the Theoretical and Estimated Item Discrimination Parameters Obtained by Excluding All Items Whose Theoretical Item Difficulty Parameters Are Outside the Interval $(-\sqrt{3}, \sqrt{3})$, Case 4, 500 Subject Case.

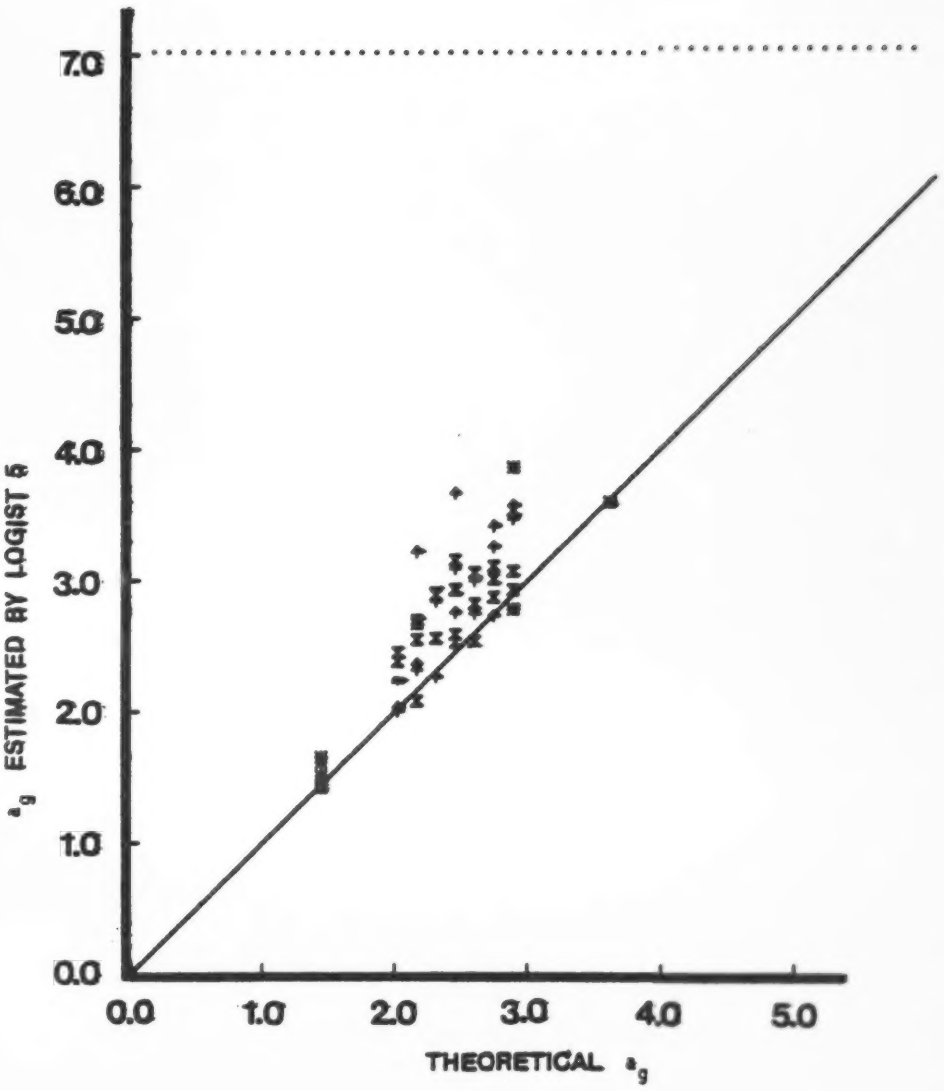

FIGURE 4-20 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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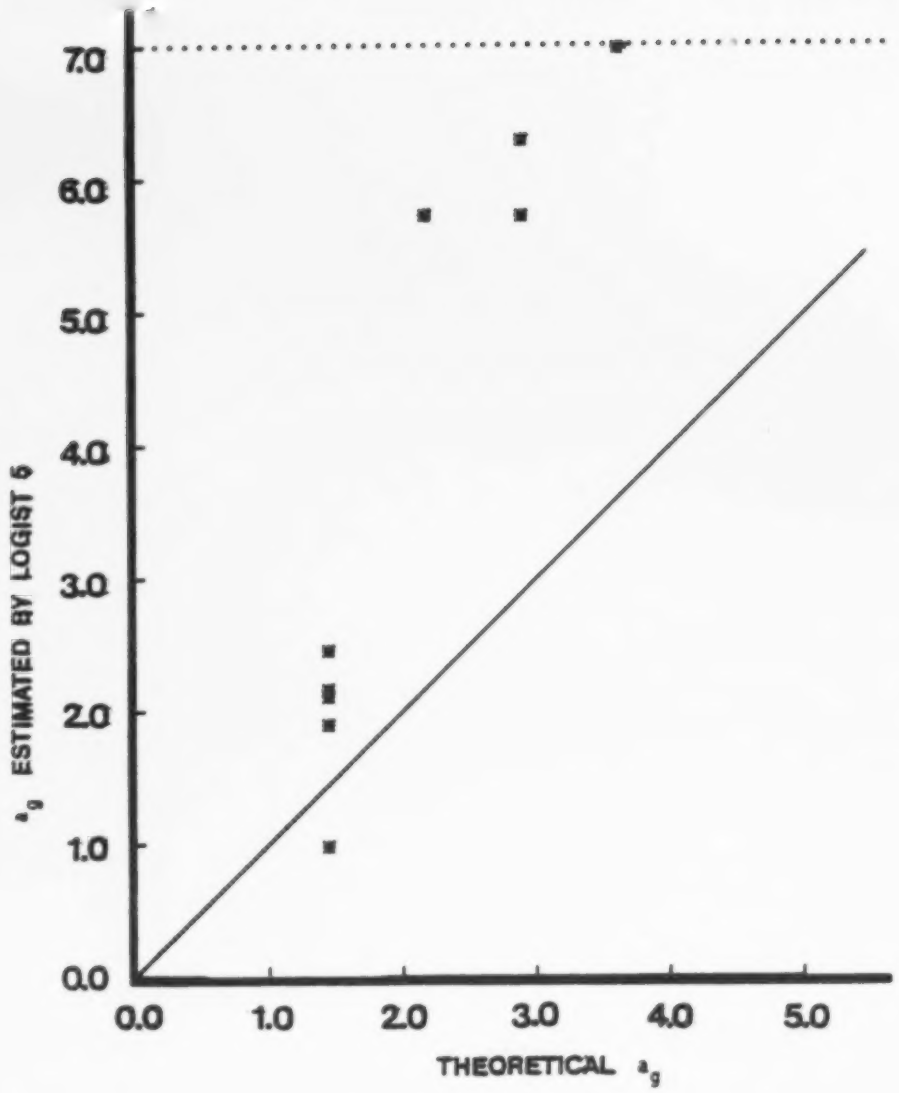

FIGURE 4-21

Reduced Scatter Diagram of the Theoretical and Estimated Item Discrimination Parameters Obtained by Excluding All Items Whose Theoretical Item Difficulty Parameters Are Outside the Interval $(-\sqrt{3}, \sqrt{3})$. Case 1, 2,000 Subject Case.

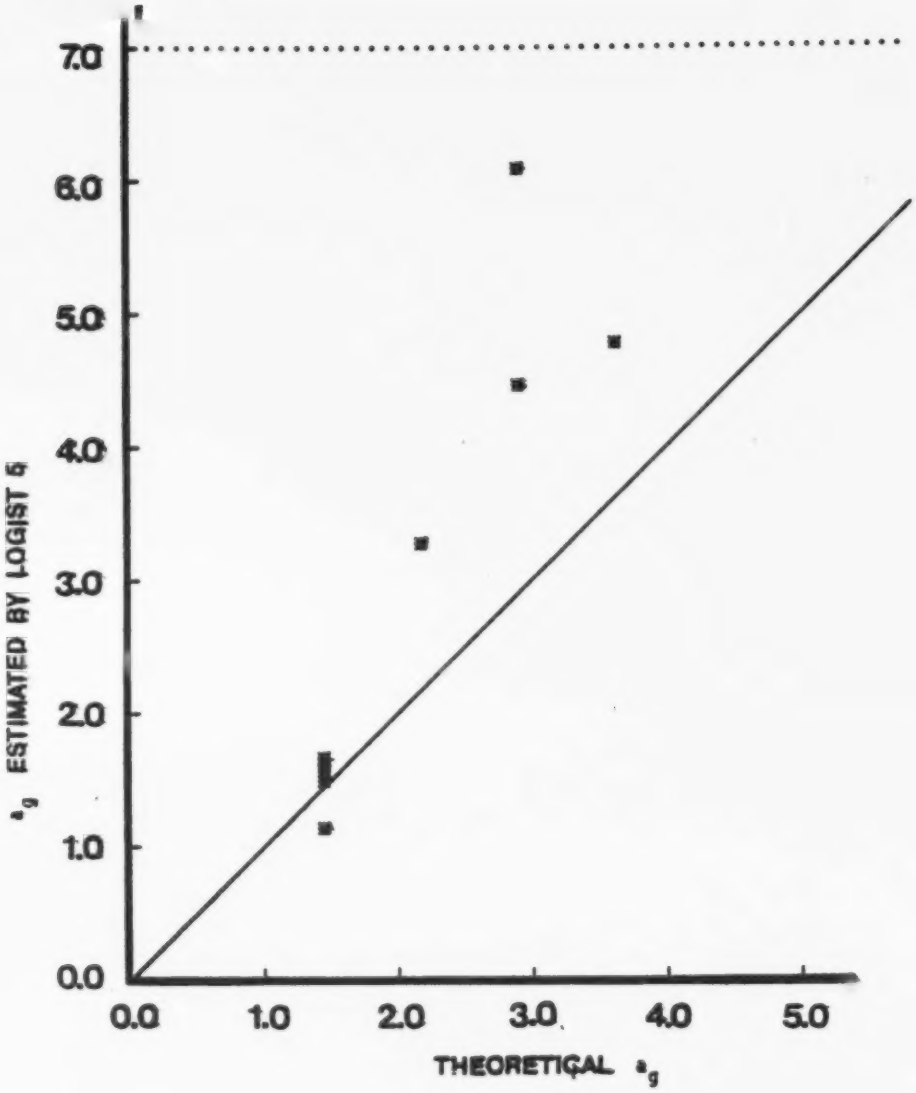

FIGURE 4-21 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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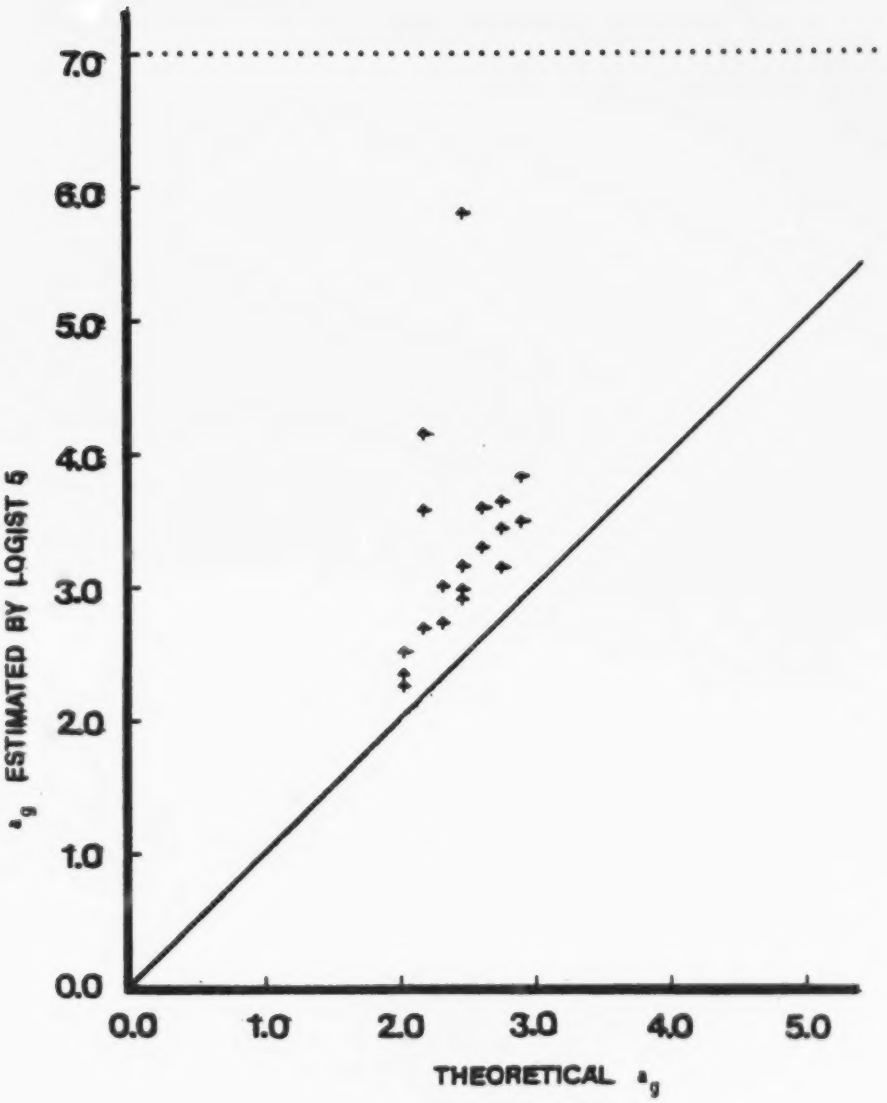

FIGURE 4-22

Reduced Scatter Diagram of the Theoretical and Estimated Item Discrimination Parameters Obtained by Excluding All Items Whose Theoretical Item Difficulty Parameters Are Outside the Interval $(-\sqrt{3}, \sqrt{3})$. Case 2, 2,000 Subject Case.

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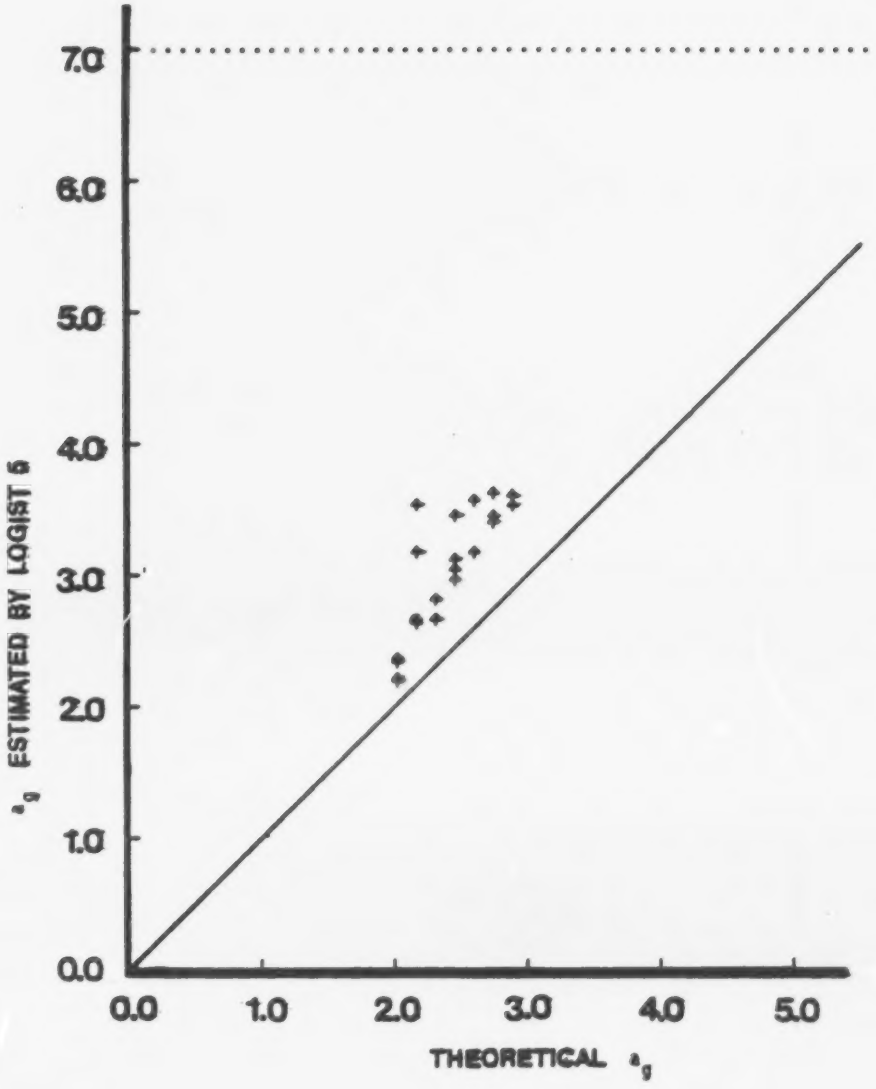

FIGURE 4-22 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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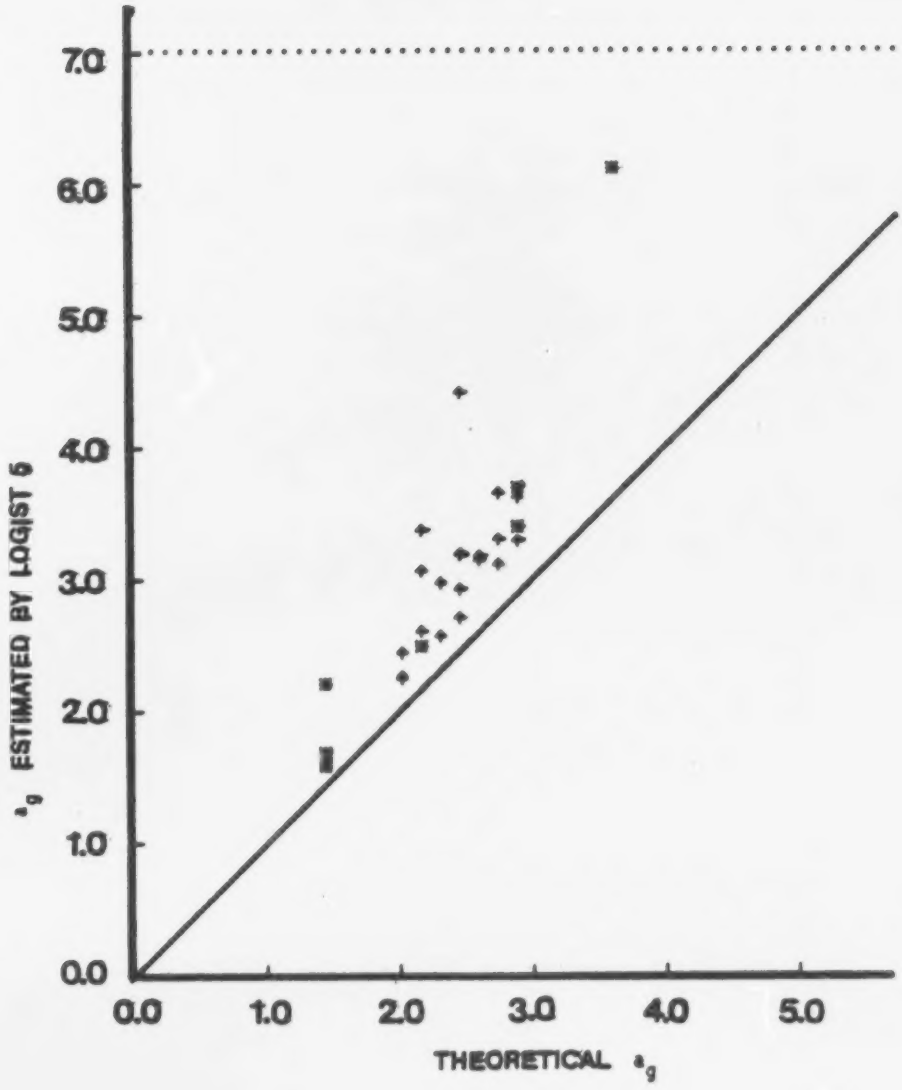

FIGURE 4-23

Reduced Scatter Diagram of the Theoretical and Estimated Item Discrimination Parameters Obtained by Excluding All Items Whose Theoretical Item Difficulty Parameters Are Outside the Interval $(-\sqrt{3}, \sqrt{3})$. Case 3, 2,000 Subject Case.

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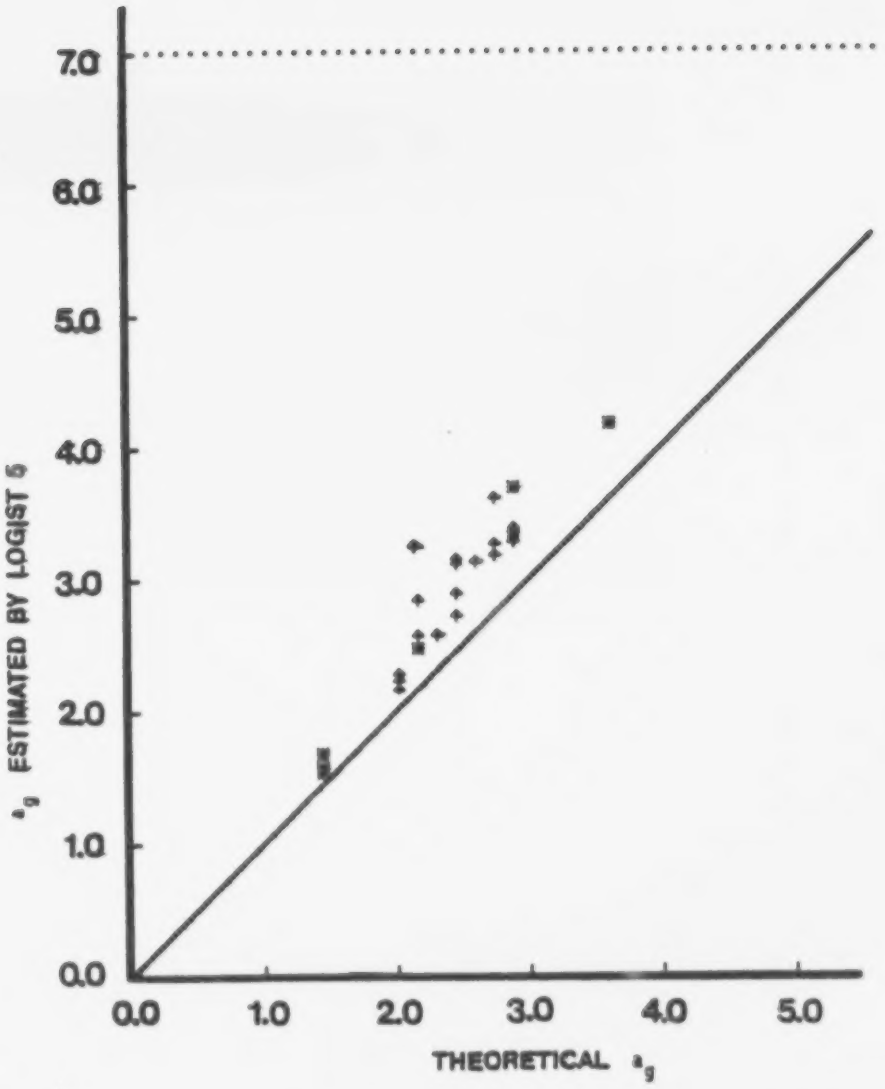

FIGURE 4-23 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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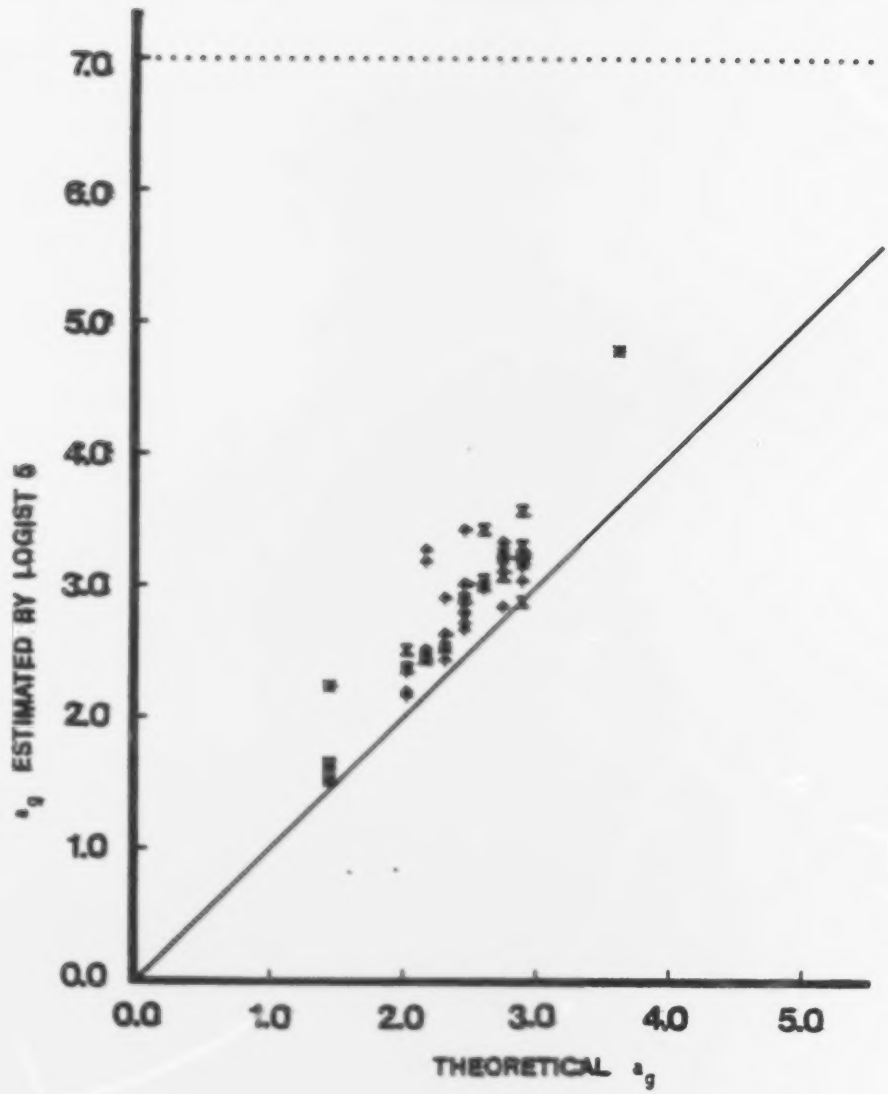

FIGURE 4-24

Reduced Scatter Diagram of the Theoretical and Estimated Item Discrimination Parameters Obtained by Excluding All Items Whose Theoretical Item Difficulty Parameters Are Outside the Interval $(-\sqrt{3}, \sqrt{3})$. Case 4, 2,000 Subject Case.

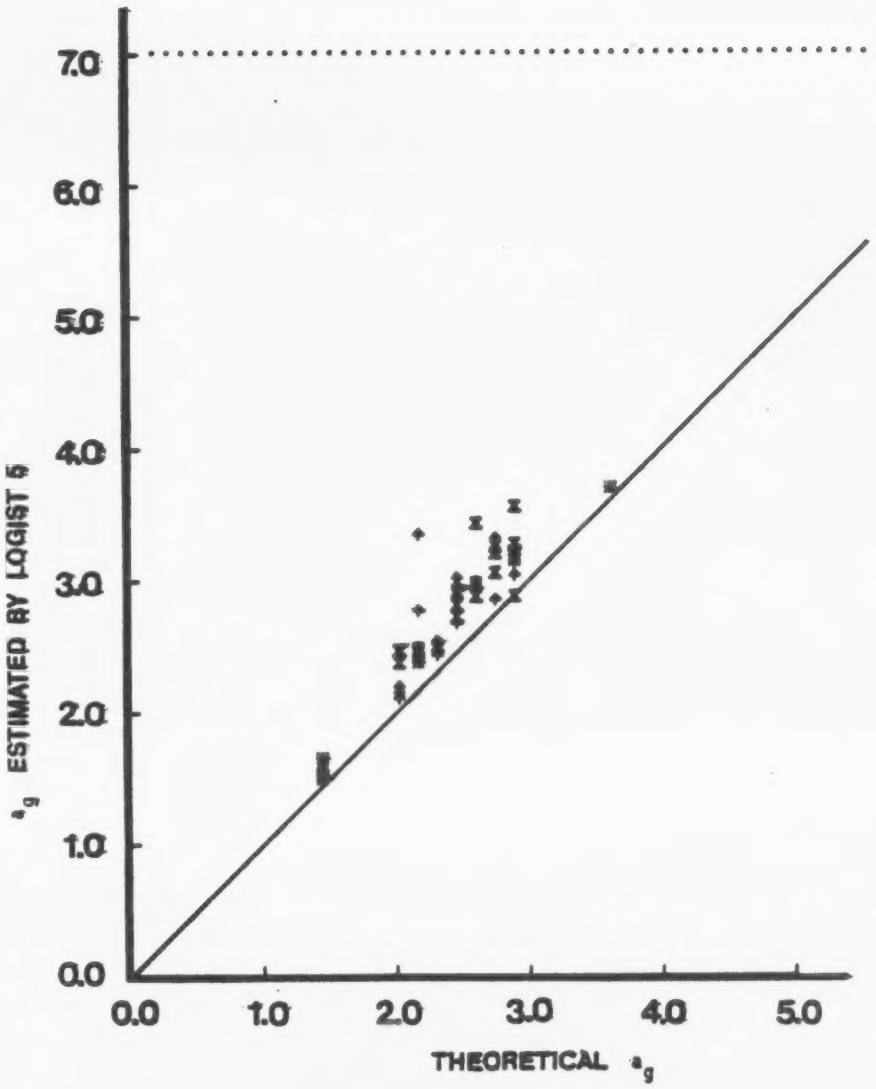

FIGURE 4-24 (Continued) : Guessing Parameter c_g^* Is Set Equal to Zero, i.e., Logistic Model Is Assumed.

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items in Case 4 adding items 52 through 70 to those twenty-eight items. The reduced scatter diagrams are shown as Figures 4-17 through 4-20 for the 500 Subject Case, and as Figures 4-21 through 4-24 for the 2,000 Subject Case, respectively. We can see a substantial improvement with respect to the error of estimation in these reduced scatter diagrams. And yet there still exists the enhancement of the estimated discrimination parameters in spite of the exclusion of those items whose errors of estimation are expected to be large.

V. Estimated Item Characteristic Functions I: Ten Item Test

Figure 5-1 presents the estimated item characteristic functions following the three-parameter logistic model and the logistic model, respectively, using the estimated item parameters obtained by Logist 5, for each item of the Ten Item Test in the 500 Subject Case. In each graph, the theoretical item characteristic function is drawn by a solid line, and the three estimated item characteristic functions in Cases 1, 3 and 4 are represented by dotted, short dashed and long dashed lines, respectively. For each curve whose estimated item discrimination parameter assumes the upper limit set in using Logist 5, an * is attached with that maximal value accompanied in parentheses. In each graph, the interval of θ, $(-\sqrt{3}, \sqrt{3})$, for which the ability distribution is uniform, is indicated by two arrows pointing to the abscissa.

In this figure, we find substantial differences between the results obtained by assuming the three-parameter logistic model and

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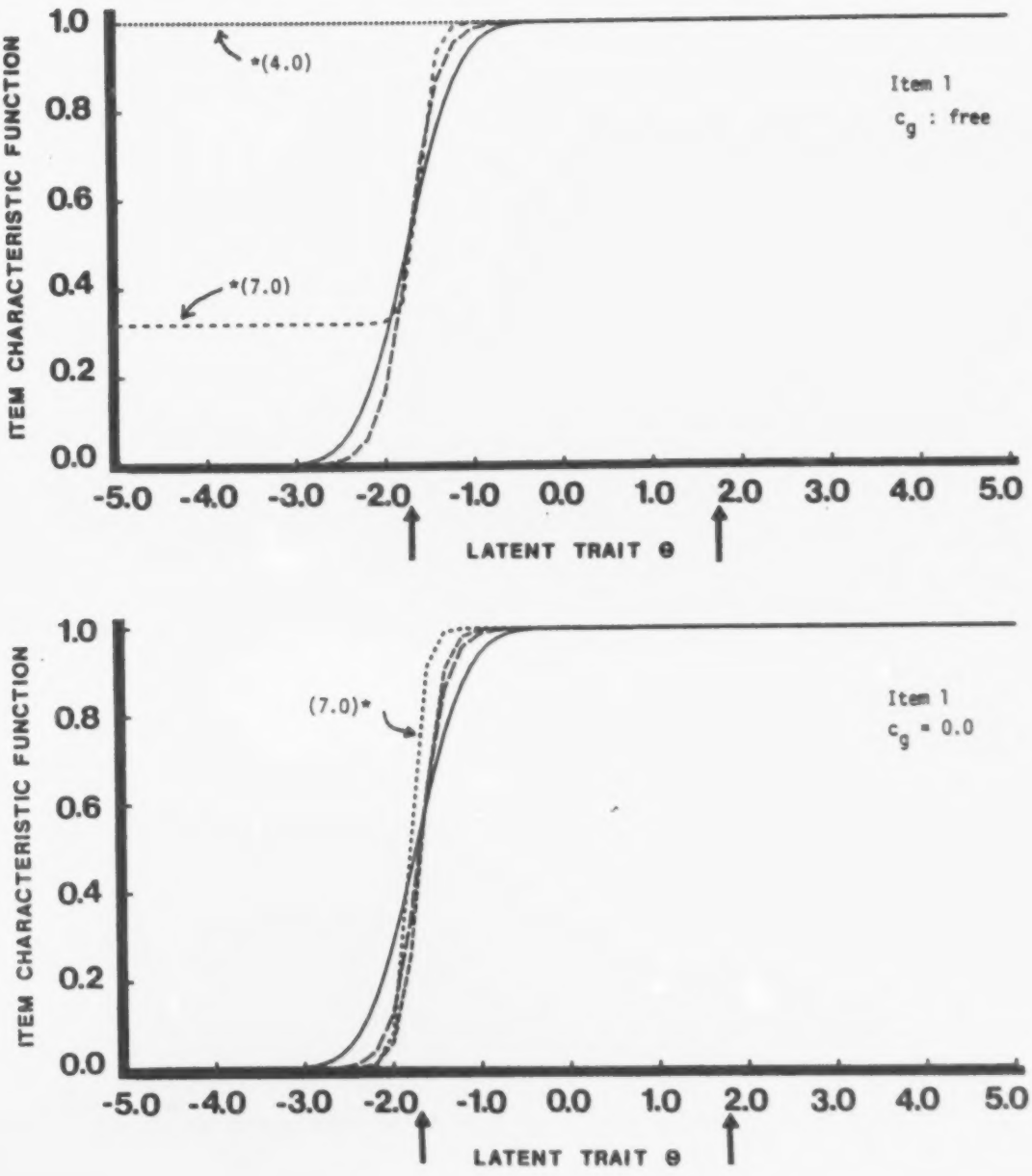

FIGURE 5-1

Theoretical Item Characteristic Function (Solid Line) of Each Item of the Ten Item Test Following the Normal Ogive Model, And Its Three Estimated Item Characteristic Functions Following the Three-Parameter Logistic Model Using LOGIST 5 , Which Are Based upon the Ten Items (Dotted Line), the Forty-Five Items (Short Dashed Line) And the Eighty Items (Long Dashed Line), Respectively. The Guessing Parameter Is Set Free in the Upper Graph, And Set Equal to Zero in the Lower Graph. 500 Subject Case.

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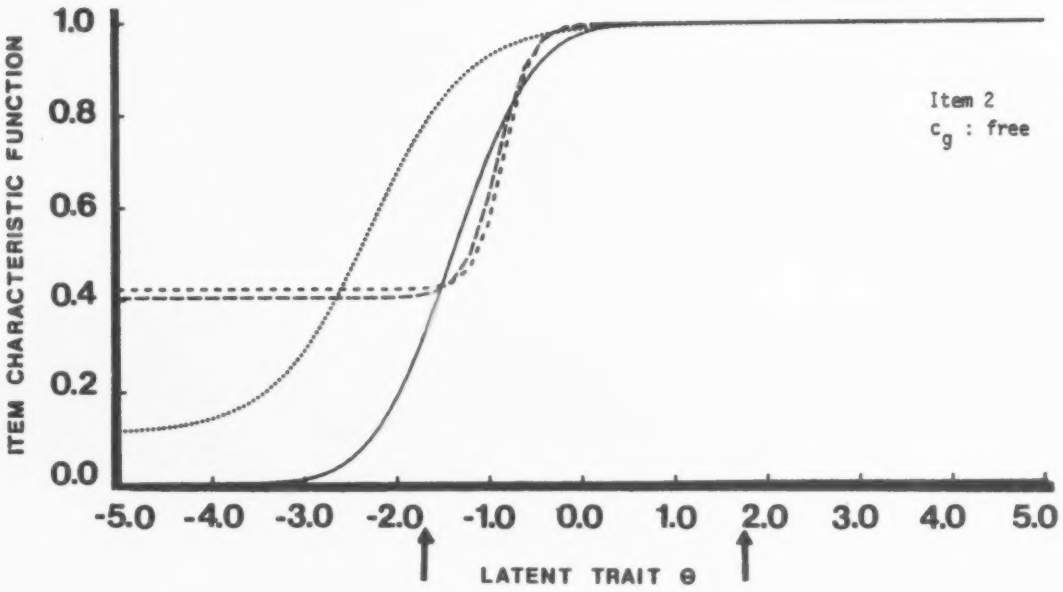


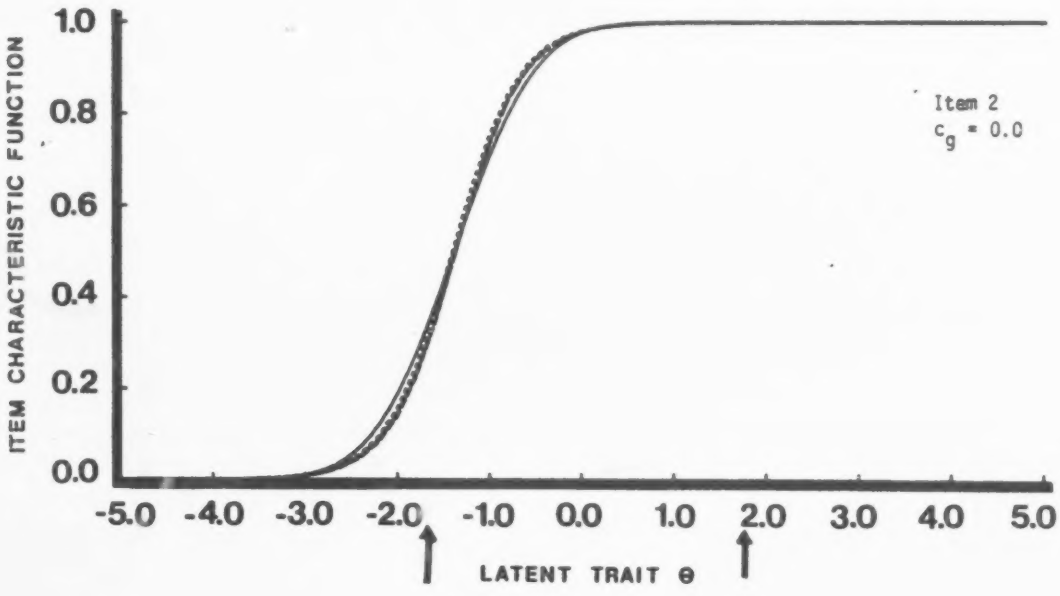
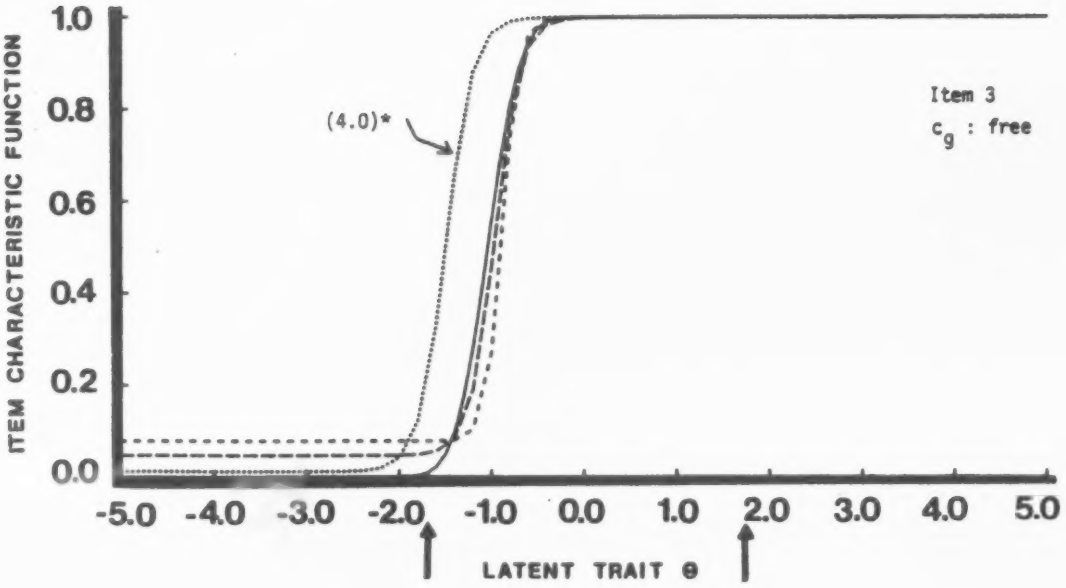


FIGURE 5-1 (Continued)

Ten Item Test, 500 Subject Case



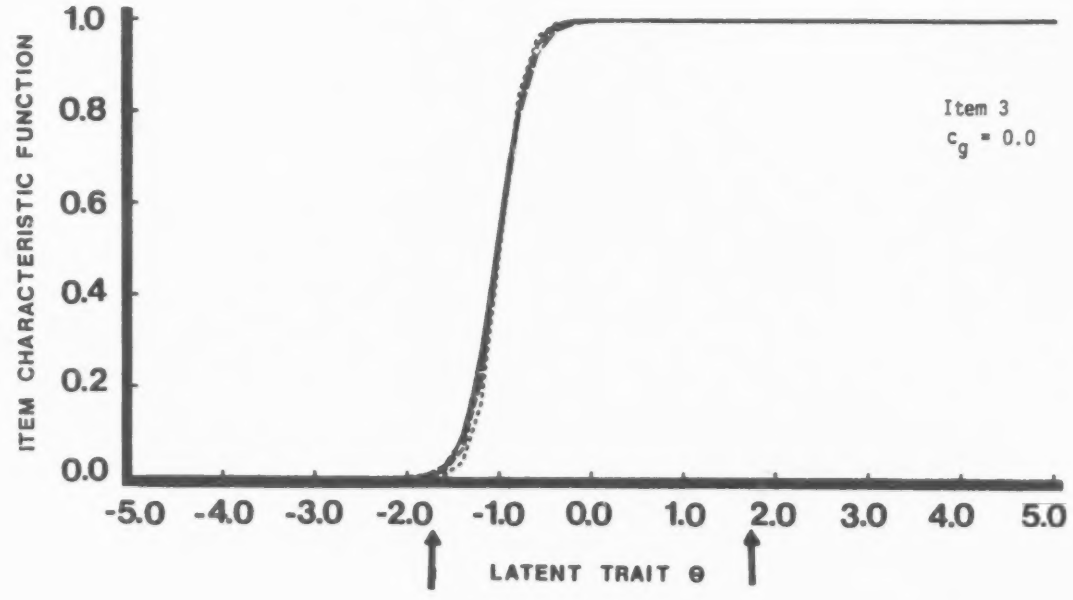


FIGURE 5-1 (Continued)

Ten Item Test, 500 Subject Case

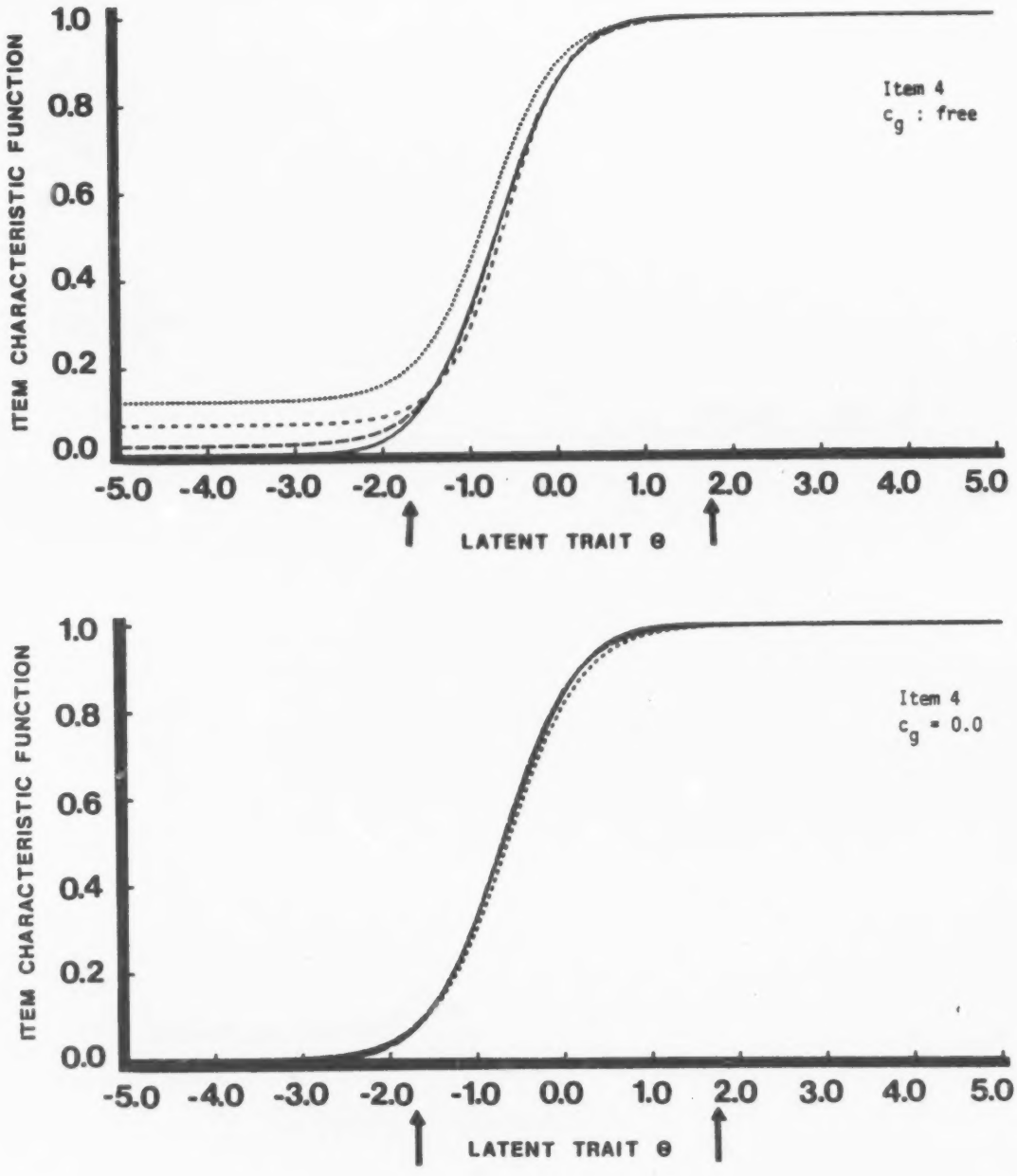


FIGURE 5-1 (Continued)

Ten Item Test, 500 Subject Case

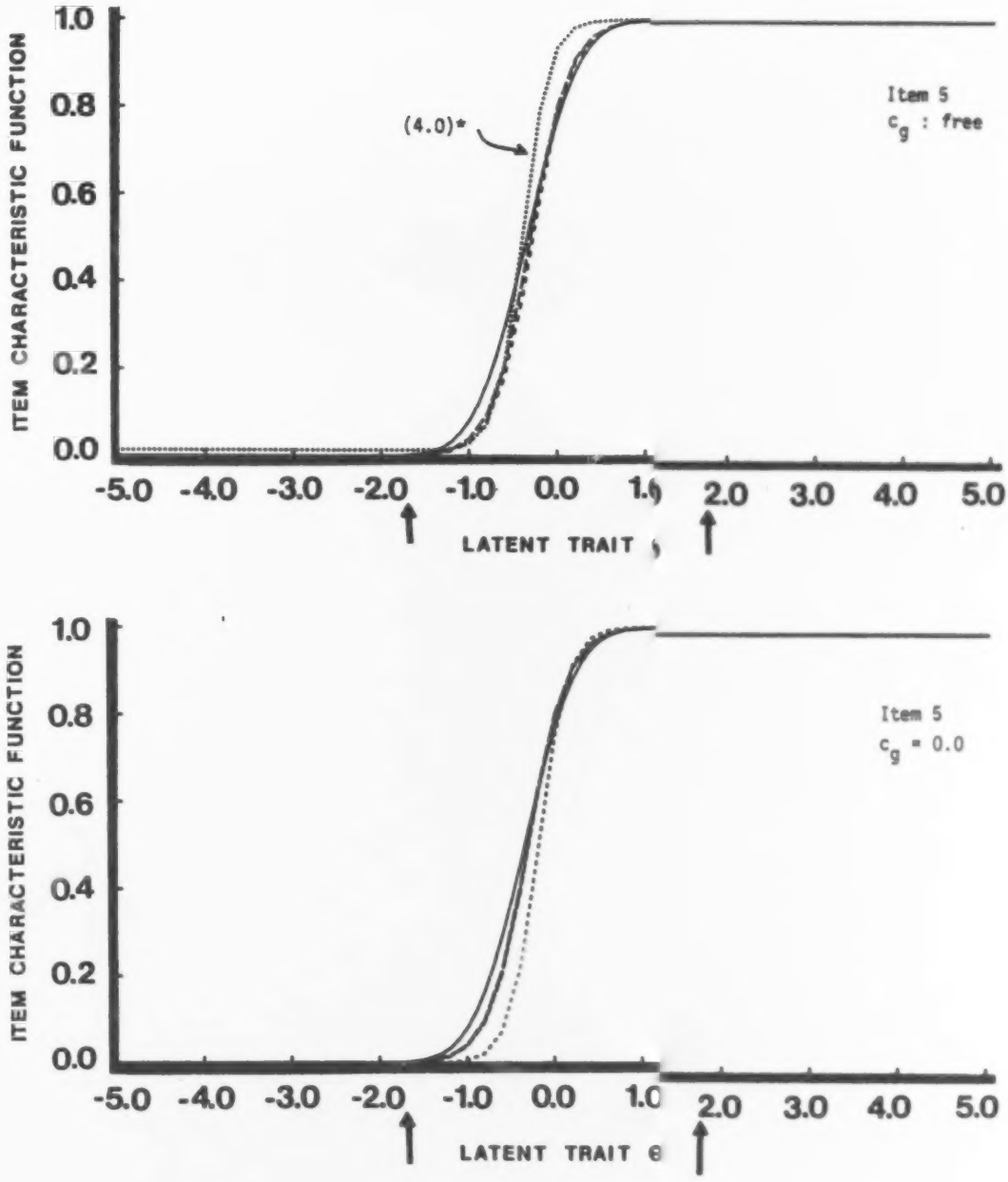


FIGURE 5-1 (Continued)

Ten Item Test, 500 Subject Case

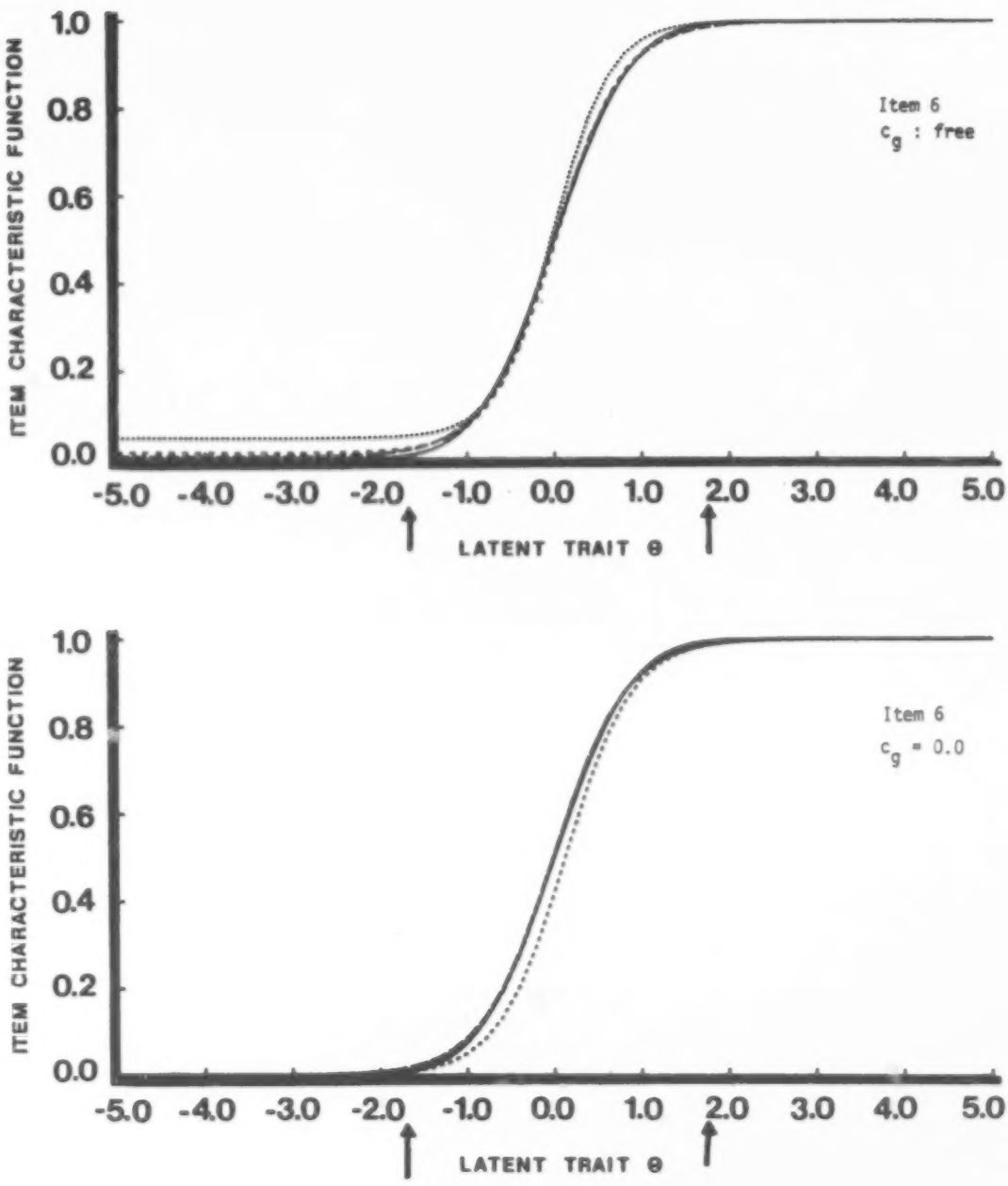


FIGURE 5-1 (Continued)

Ten Item Test, 500 Subject Case

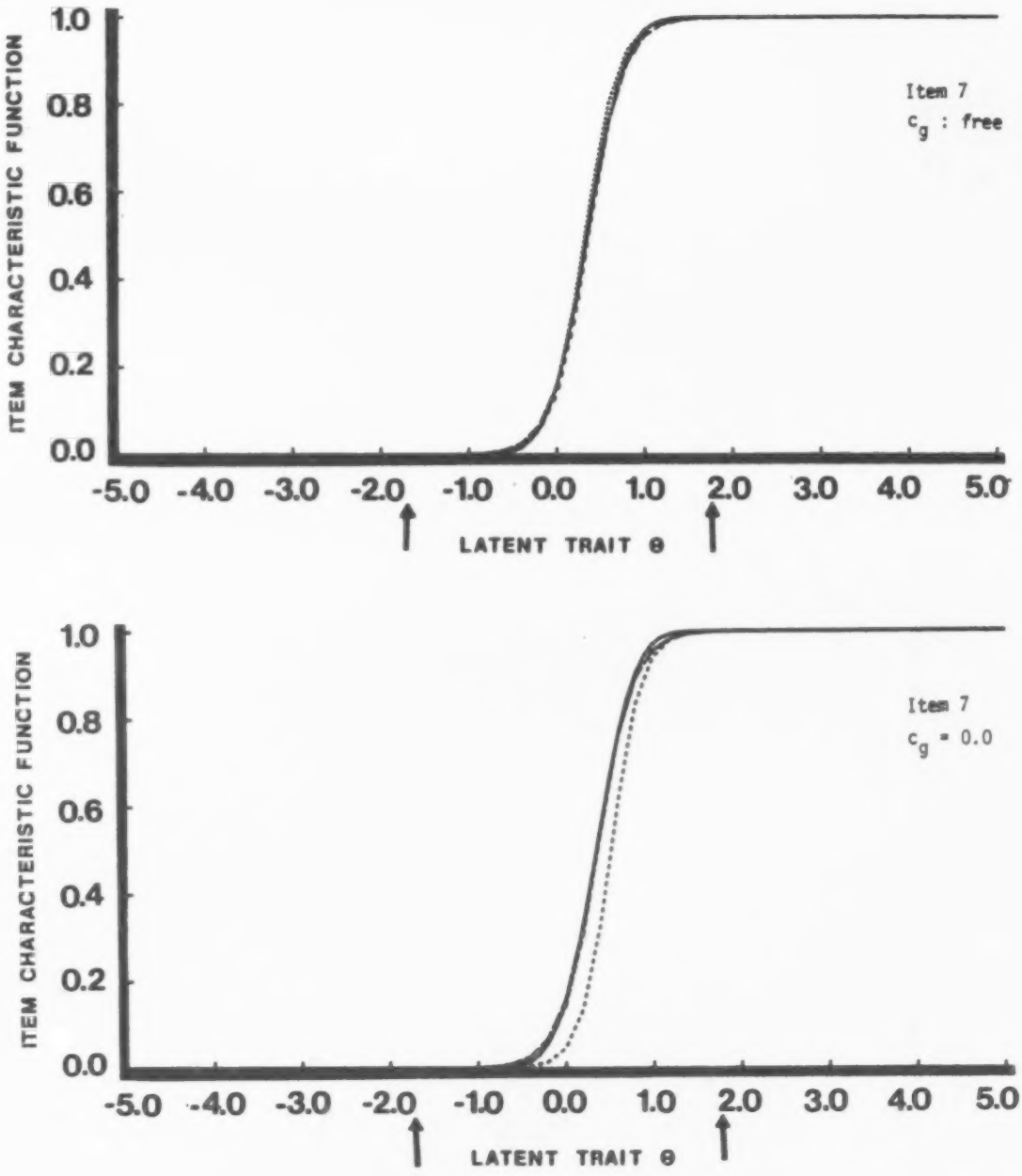
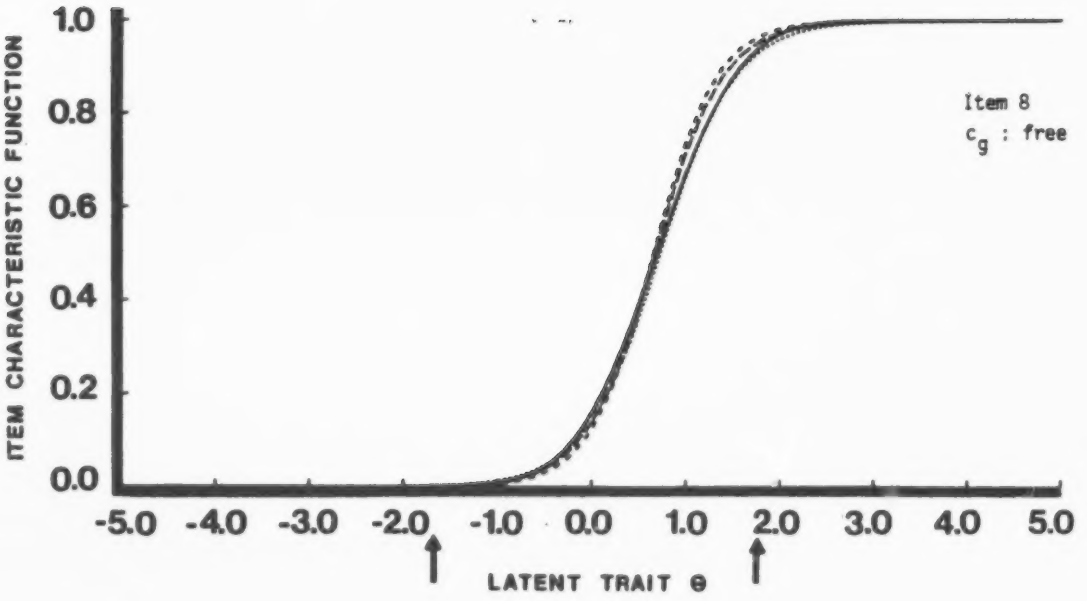


FIGURE 5-1 (Continued)

Ten Item Test, 500 Subject Case



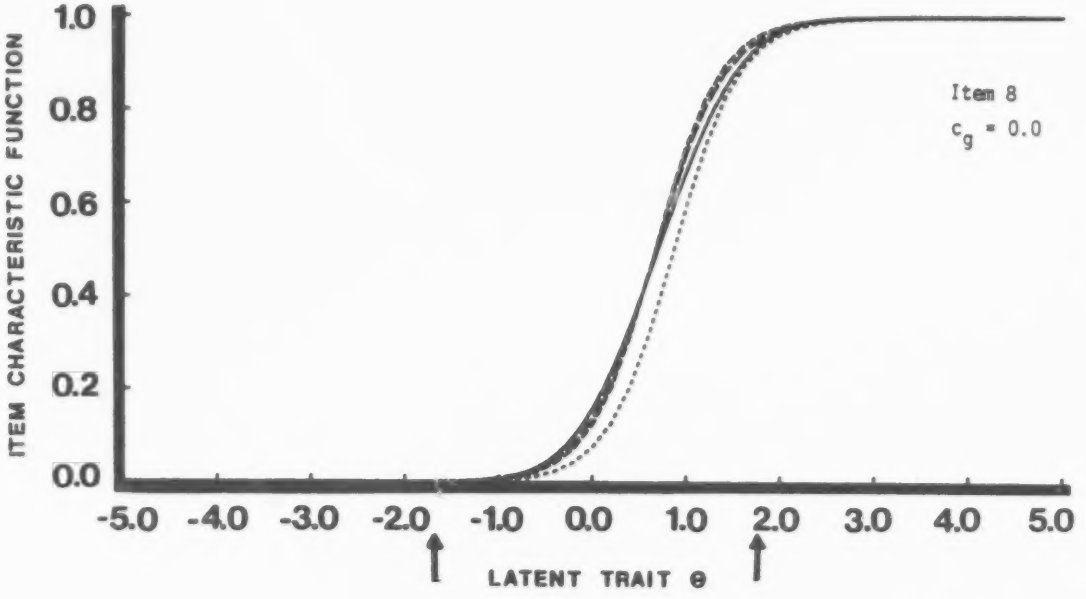
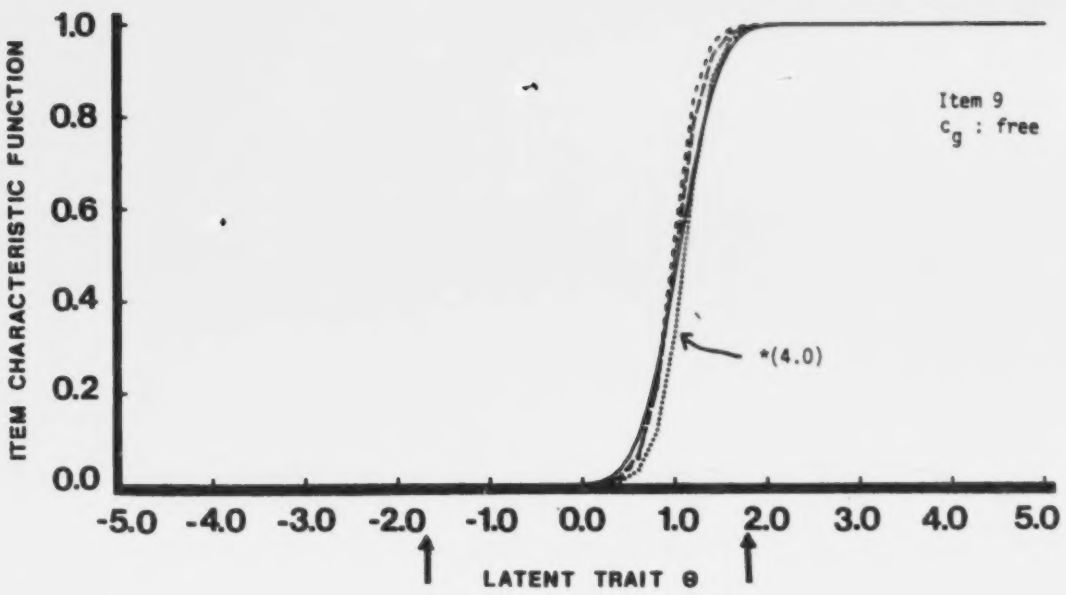


FIGURE 5-1 (Continued)

Ten Item Test, 500 Subject Case



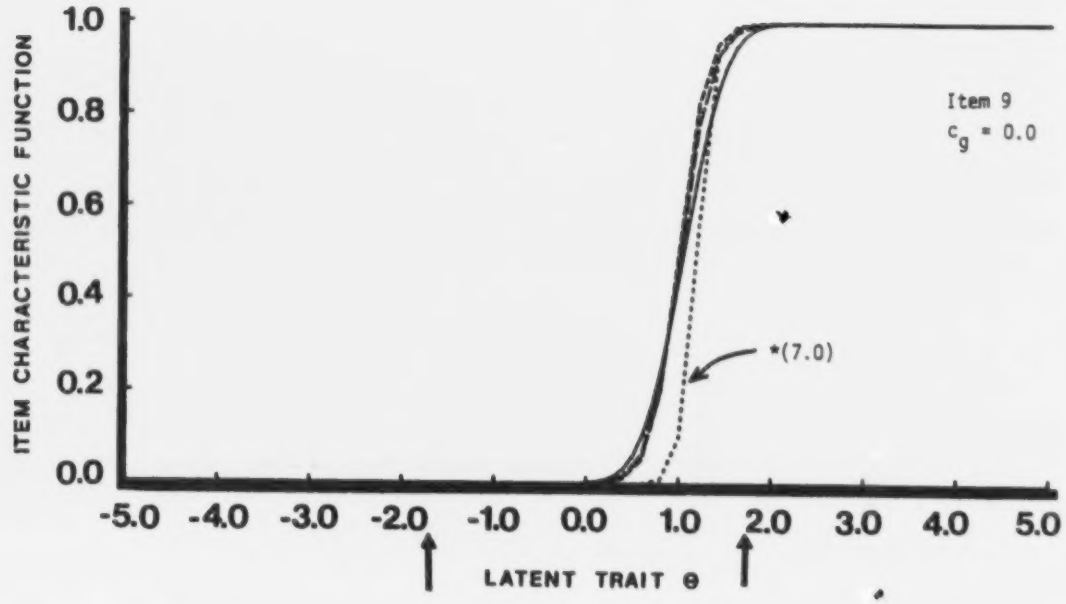
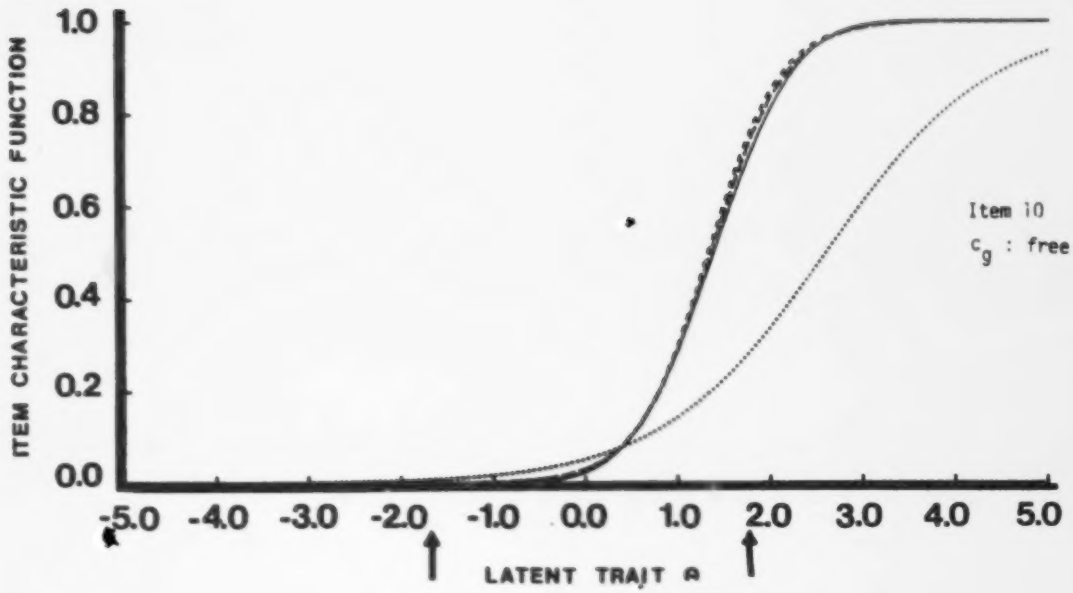


FIGURE 5-1 (Continued)

Ten Item Test, 500 Subject Case



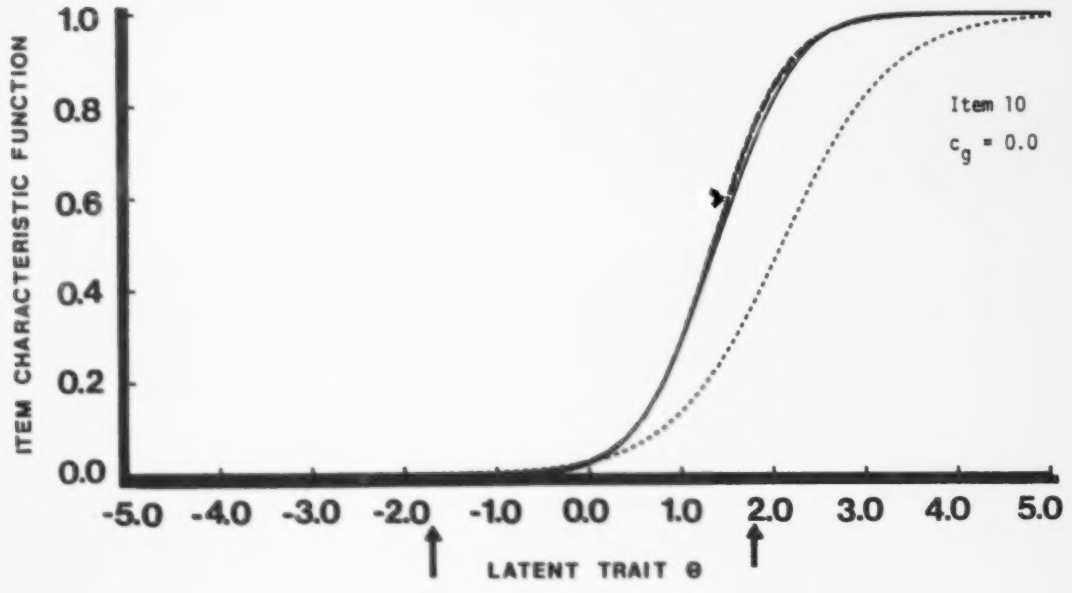


FIGURE 5-1 (Continued)

Ten Item Test, 500 Subject Case

those obtained by assuming the logistic model, i.e., the fit of the estimated item characteristic functions to the corresponding theoretical functions are poorer in general when the three-parameter logistic model is assumed. For the items whose theoretical item difficulty parameters are close to the midpoint of the interval $(-\sqrt{3}, \sqrt{3})$, however, those curves are just as close to the theoretical ones as the corresponding estimated item characteristic functions obtained by assuming the logistic model, especially in Cases 3 and 4. For the items whose difficulty parameters are closer to the lower endpoint of the interval, the curves tend to be outrageously different from the theoretical curves, having big tails in the negative direction.

Figure 5-2 presents the corresponding results in the 2,000 Subject Case. In general, the estimated item characteristic functions tend to fit the theoretical ones better compared with those obtained in the 500 Subject Case, even in Case 1. Big tails are still observed, however, for items having low difficulty parameters.

VI. Estimated Item Characteristic Functions II: Thirty-Five Item Test

The results of the items of the Thirty-Five Item Test corresponding to those which were observed for the items of the Ten Item Test in the preceding section are presented as Figures 6-1 and 6-2, for the 500 and 2,000 Subject Cases, respectively. In these figures, dotted curves represent the estimated item characteristic functions of Case 2 instead of Case 1, unlike those in Figures 5-1 and

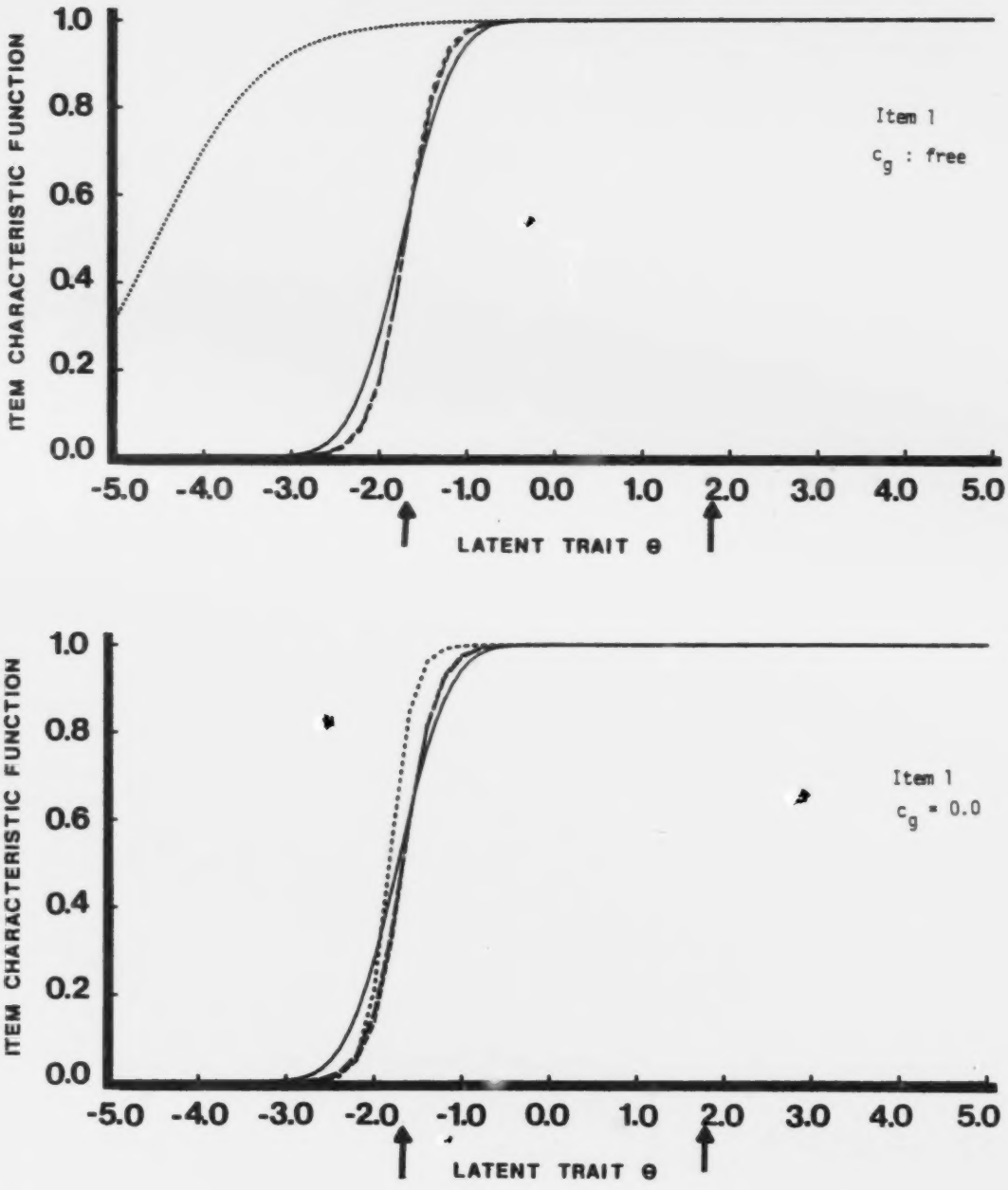
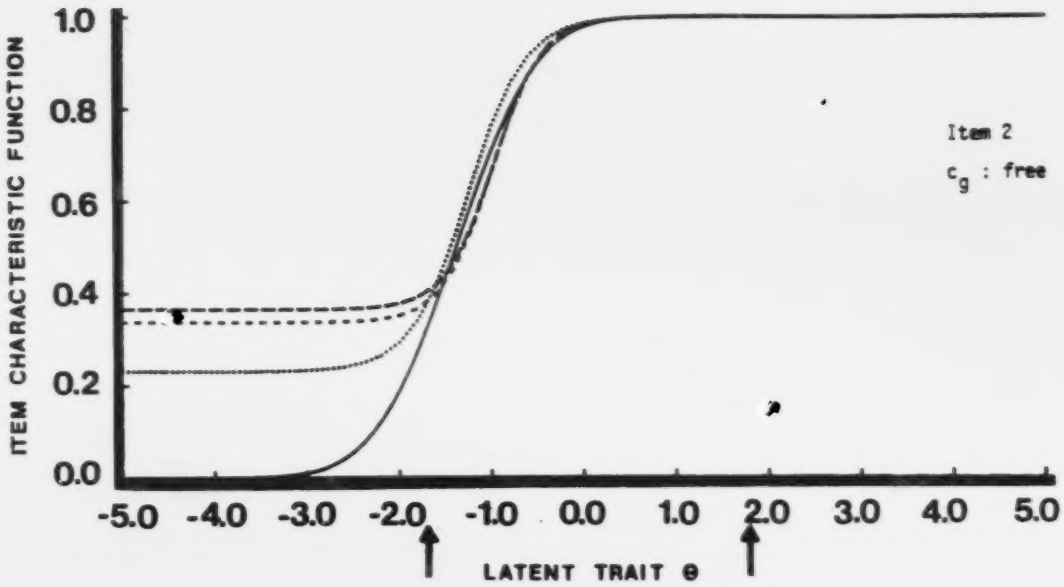


FIGURE 5-2

Theoretical Item Characteristic Function (Solid Line) of Each Item of the Ten Item Test Following the Normal Ogive Model, And Its Three Estimated Item Characteristic Functions Following the Three-Parameter Logistic Model Using LOGIST 5 , Which Are Based upon the Ten Items (Dotted Line), the Forty-Five Items (Short Dashed Line) And the Eighty Items (Long Dashed Line), Respectively. The Guessing Parameter Is Set Free in the Upper Graph, And Set Equal to Zero in the Lower Graph. 2,000 Subject Case.



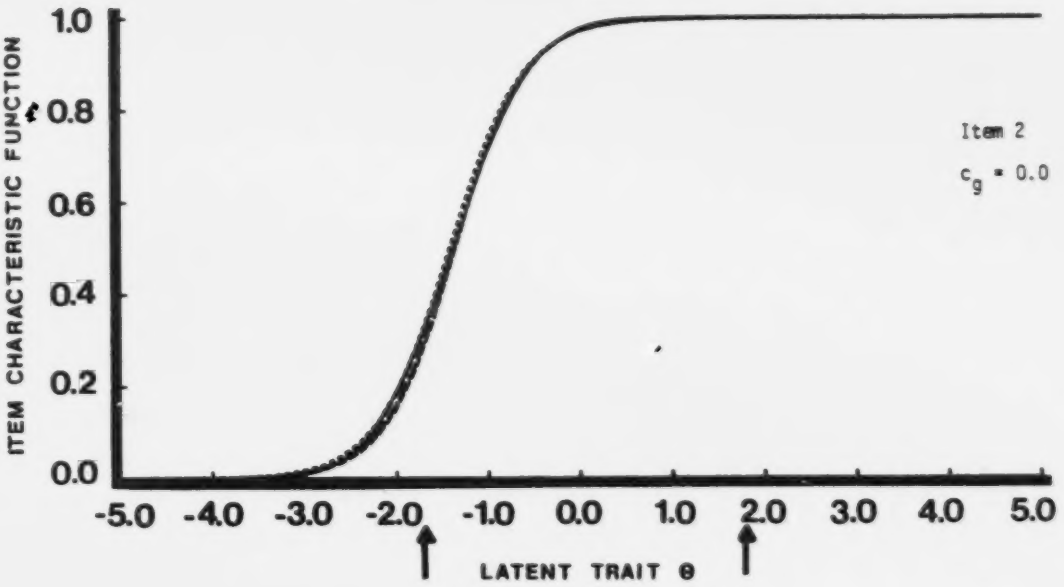


FIGURE 5-2 (Continued)

Ten Item Test, 2,000 Subject Case

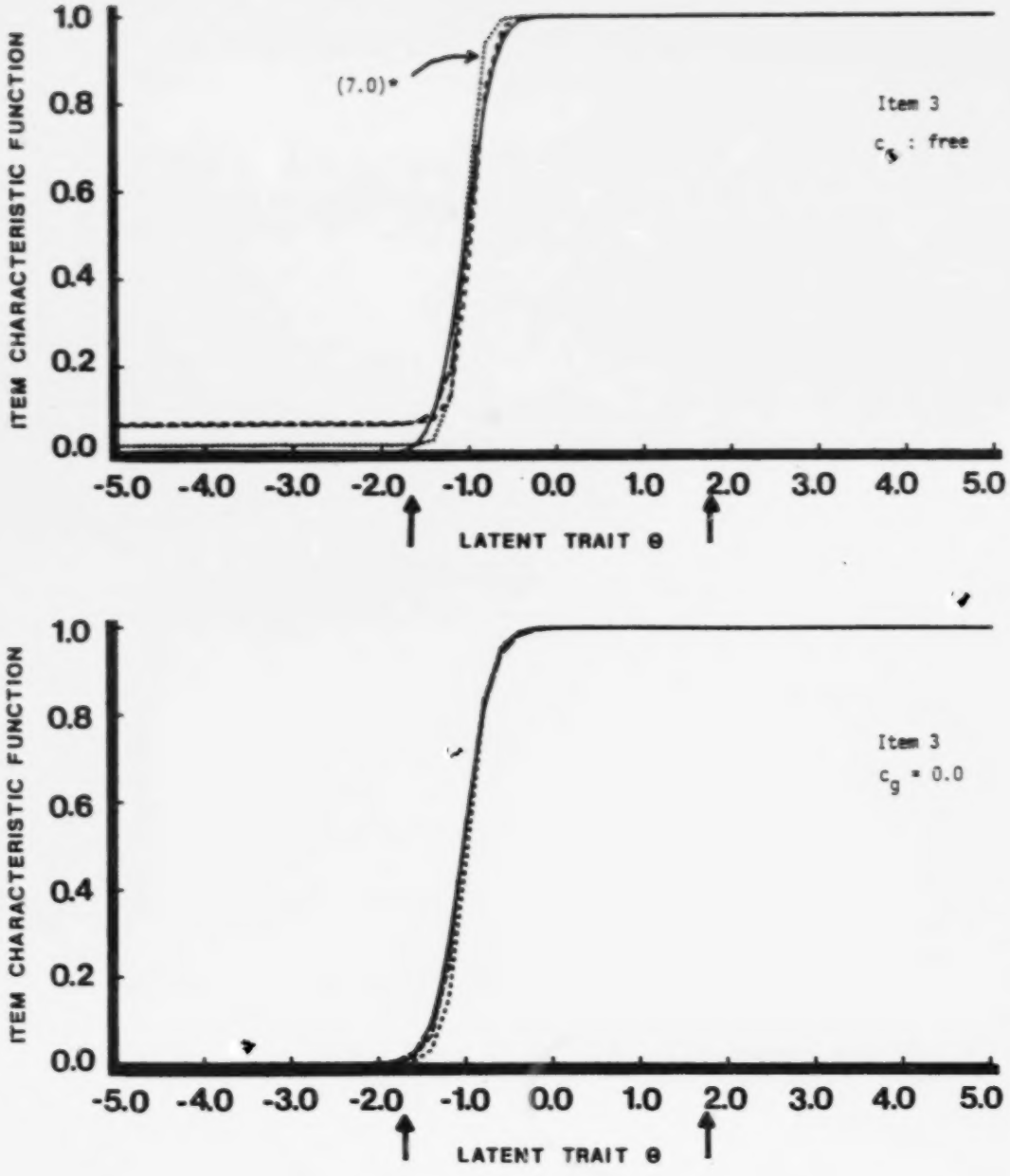


FIGURE 5-2 (Continued)

Ten Item Test, 2,000 Subject Case

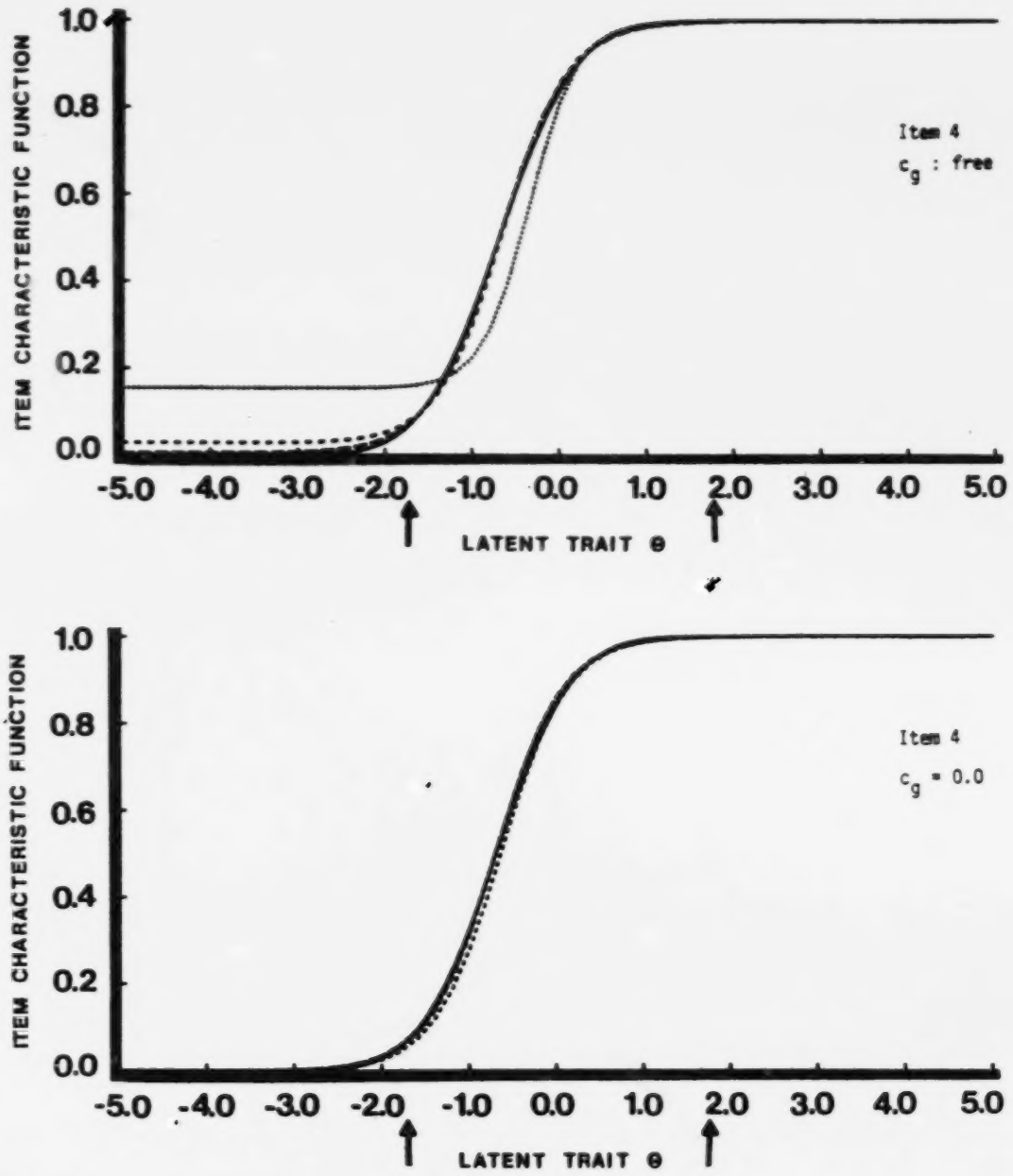


FIGURE 5-2 (Continued)

Ten Item Test, 2,000 Subject Case

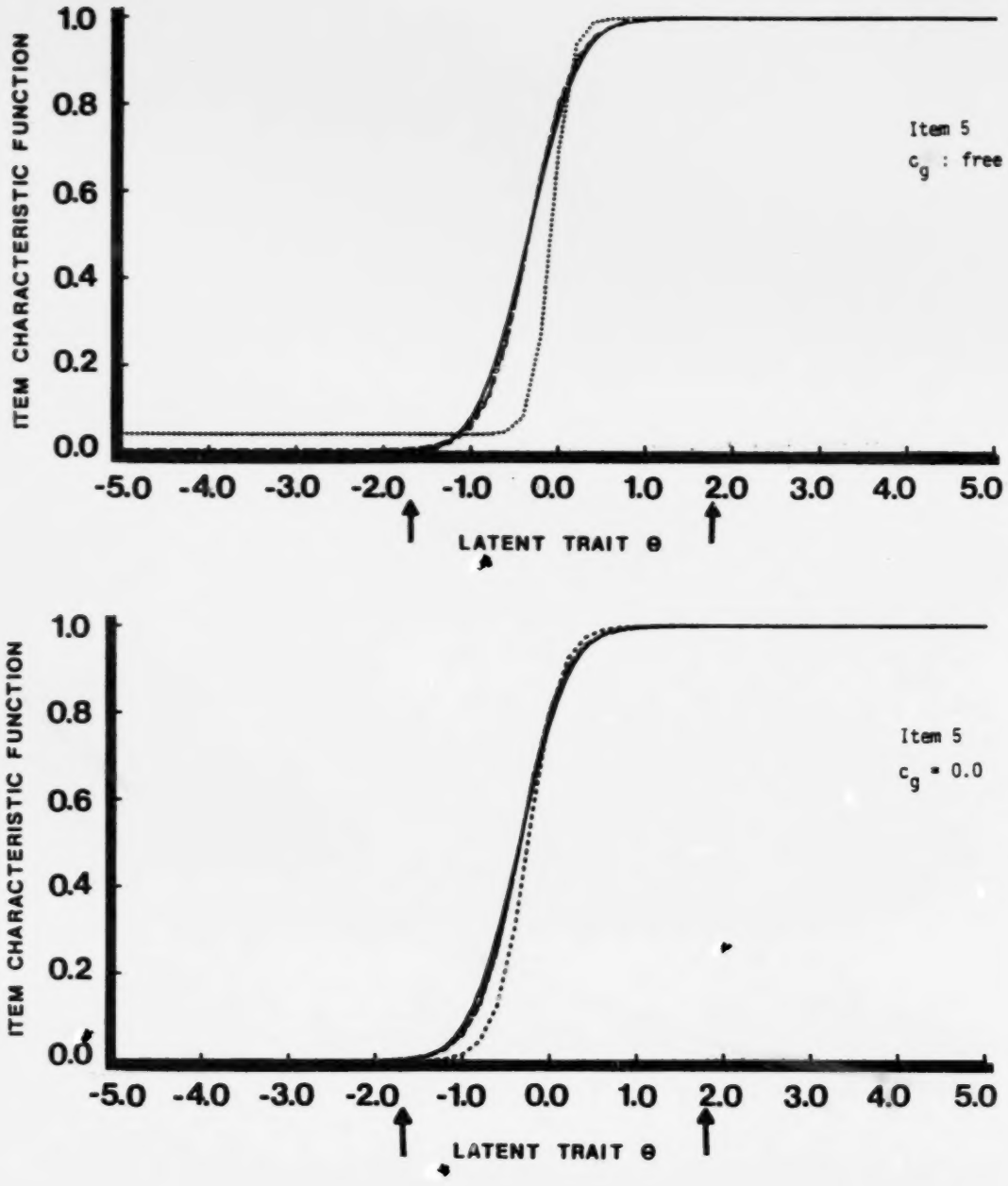
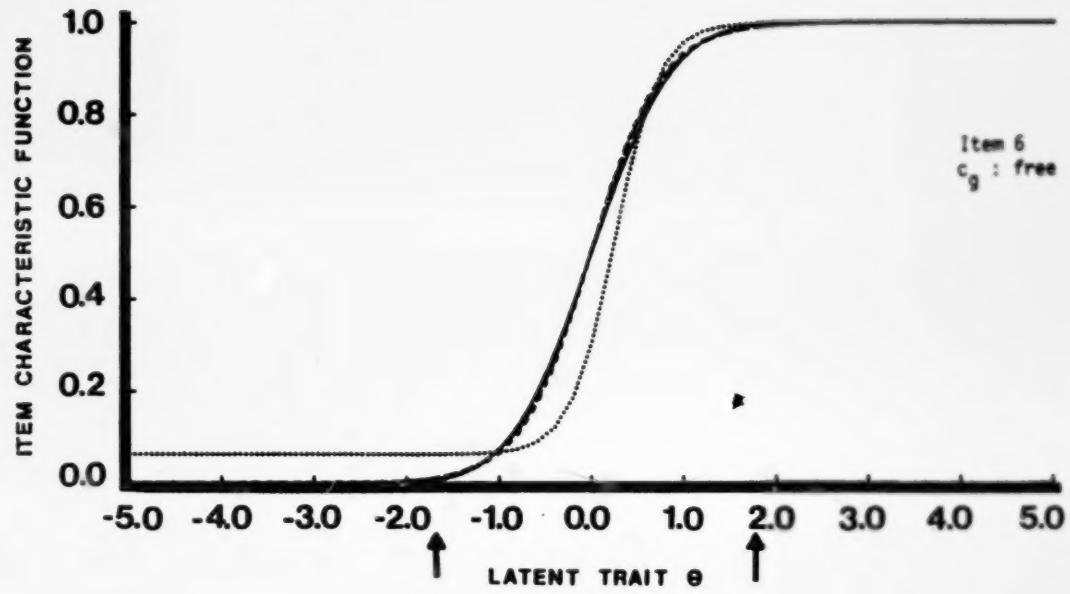


FIGURE 5-2 (Continued)

Ten Item Test, 2,000 Subject Case



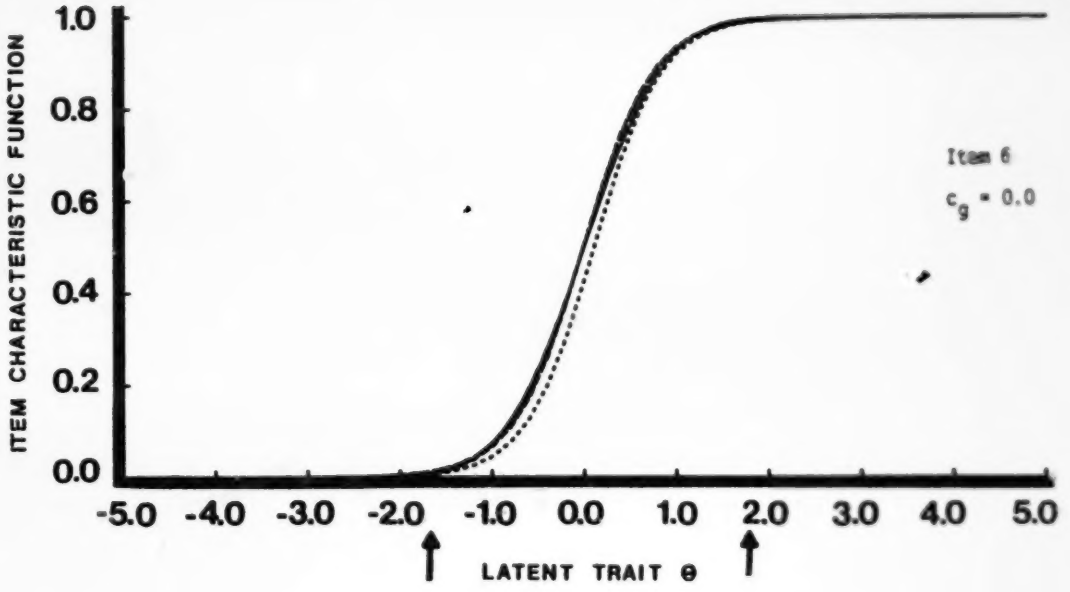


FIGURE 5-2 (Continued)

Ten Item Test, 2,000 Subject Case

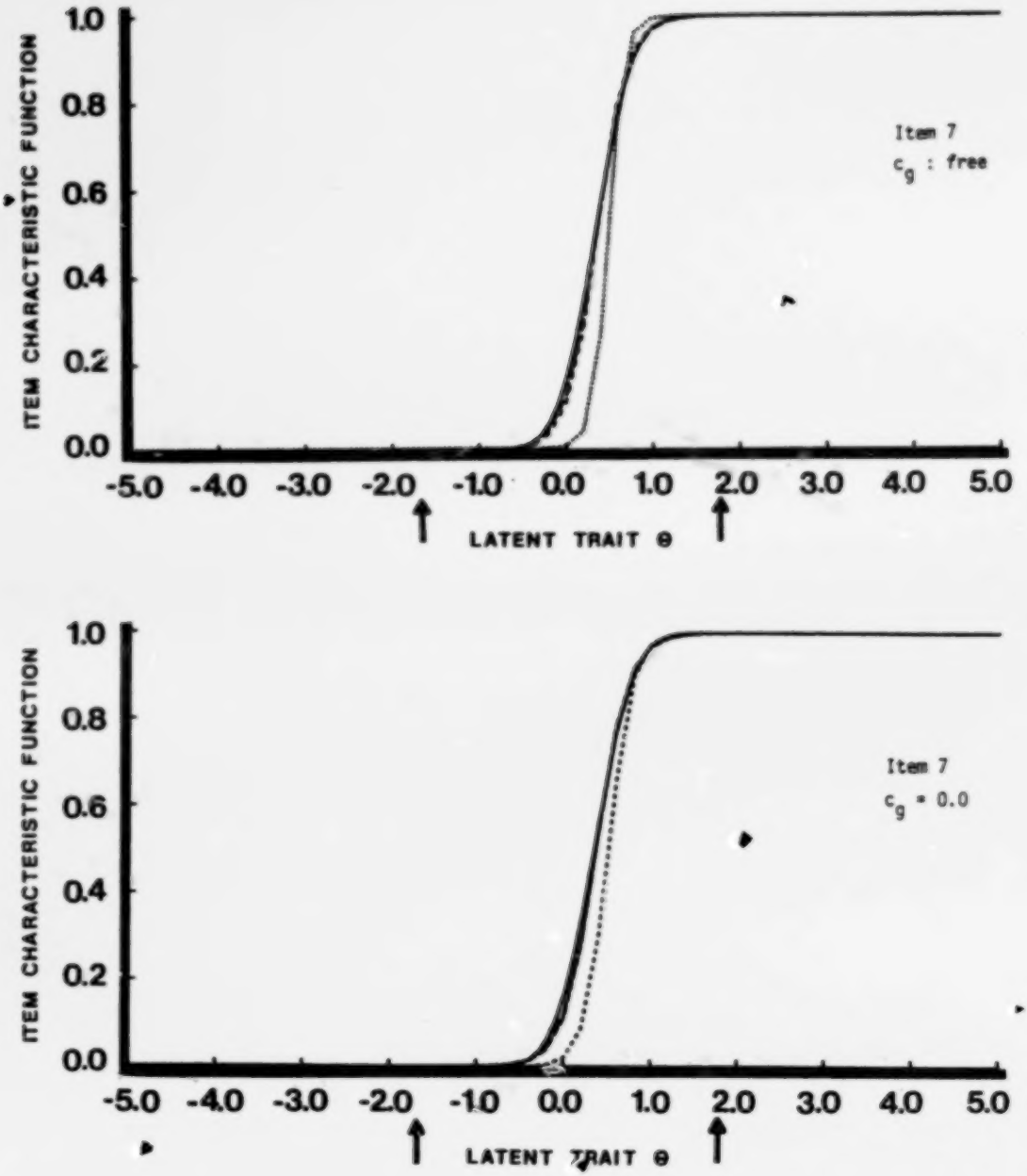


FIGURE 5-2 (Continued)

Ten Item Test, 2,000 Subject Case

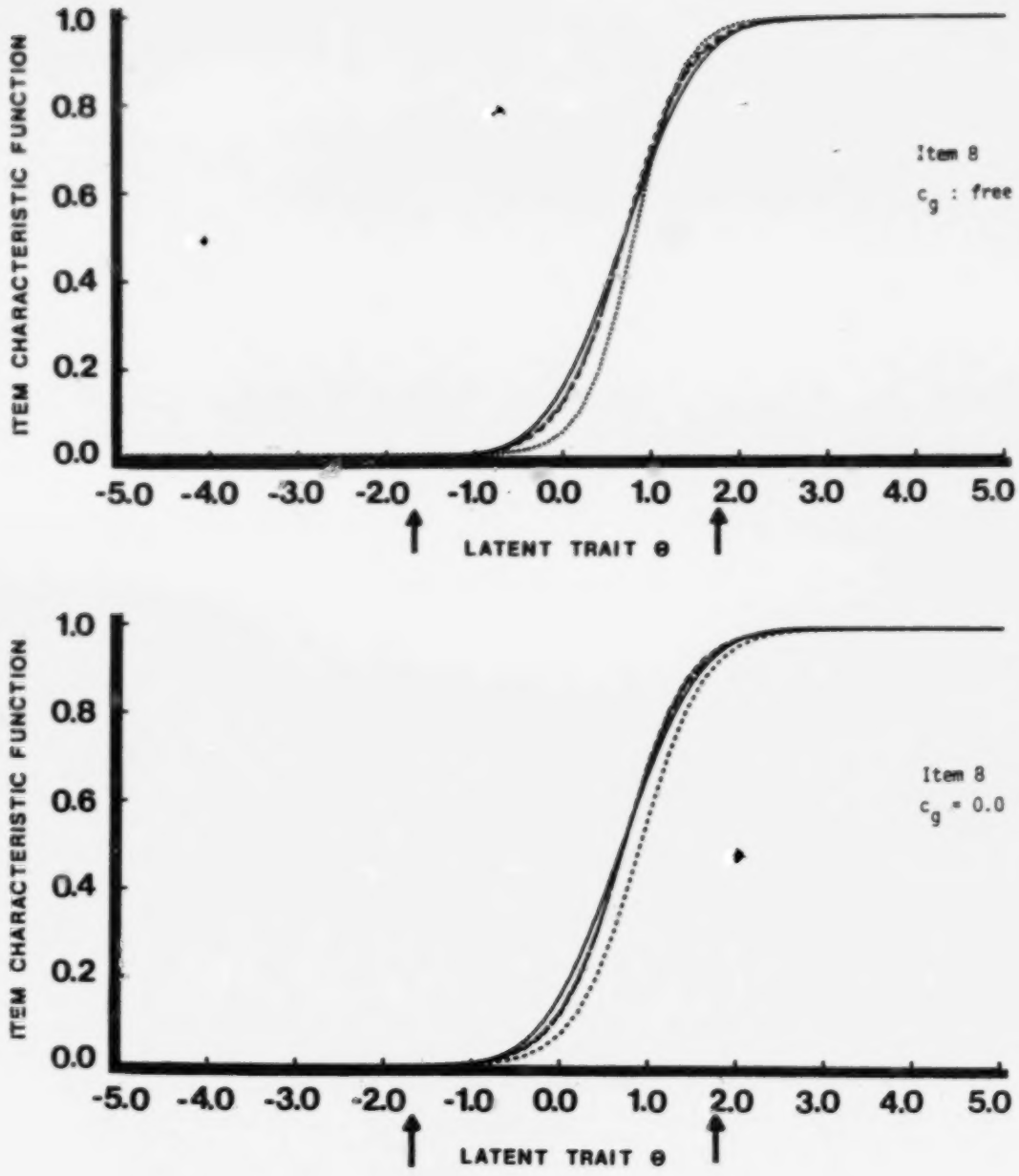


FIGURE 5-2 (Continued)

Ten Item Test, 2,000 Subject Case

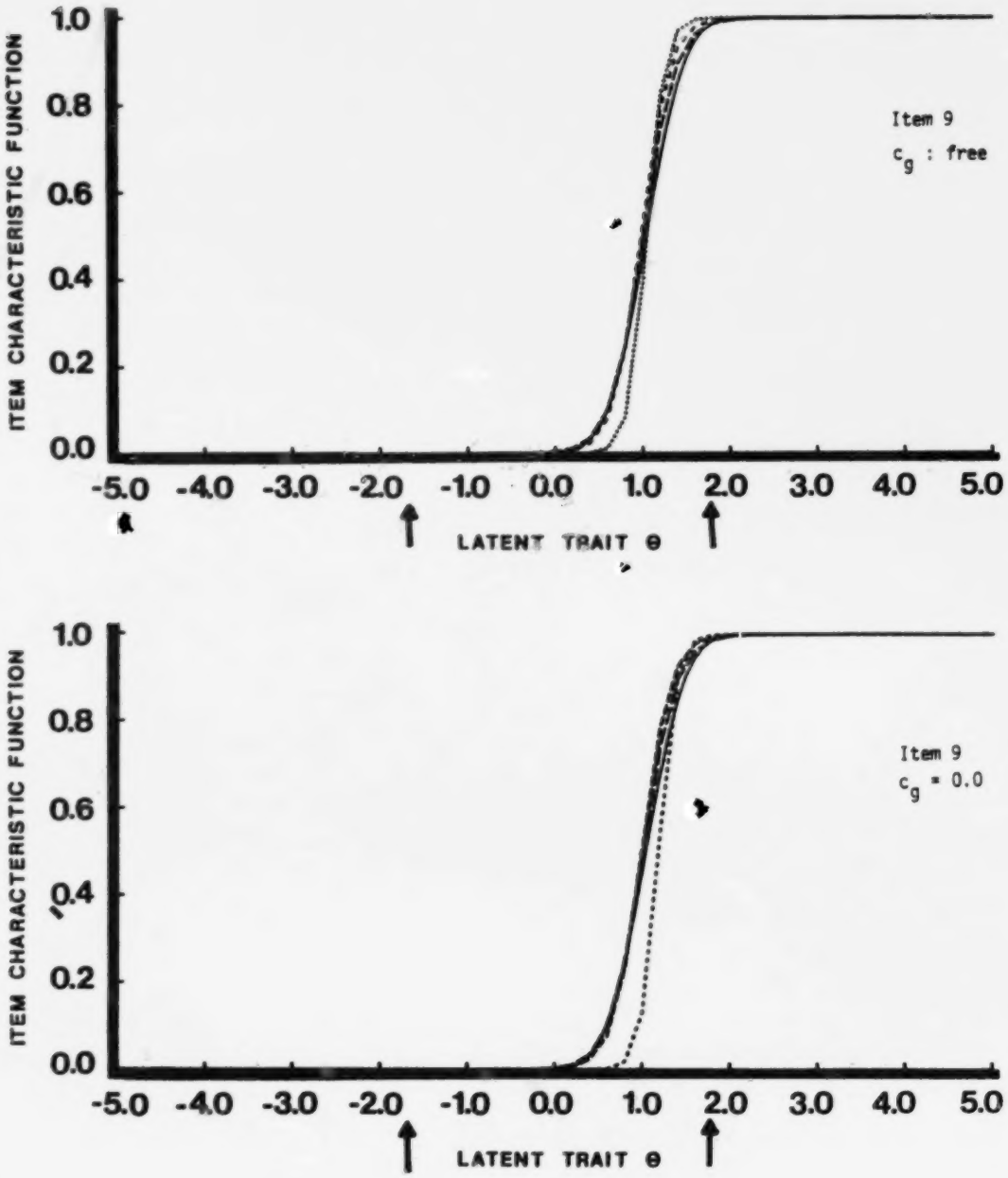
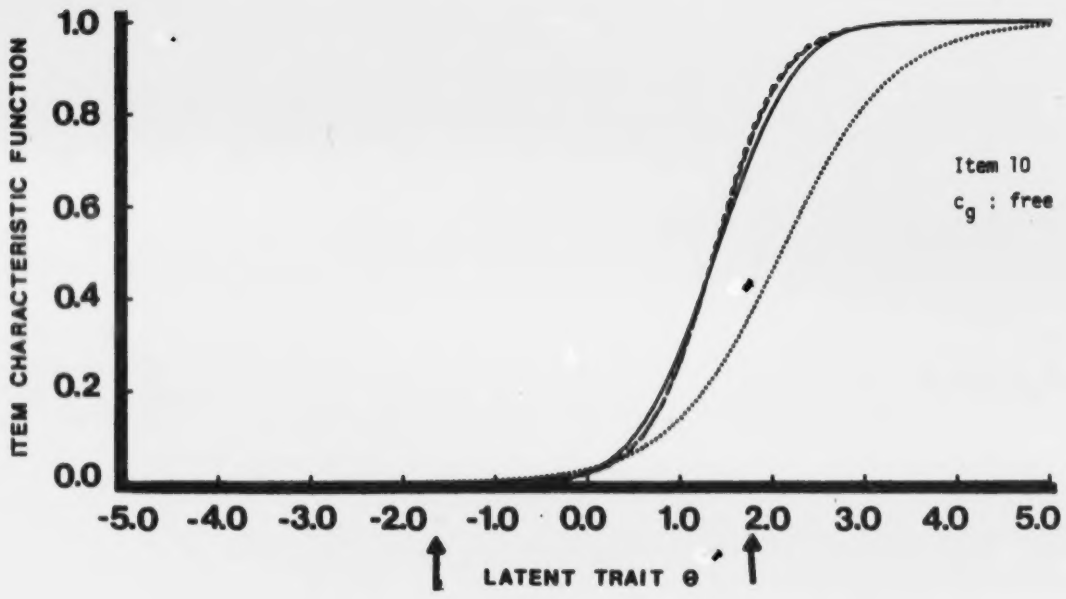


FIGURE 5-2 (Continued)

Ten Item Test, 2,000 Subject Case



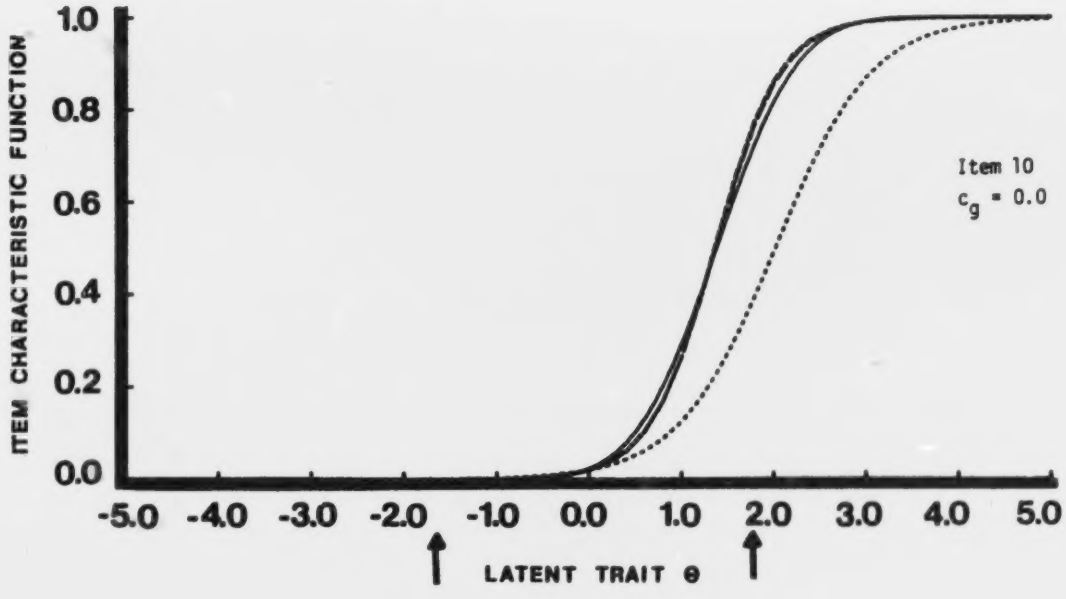


FIGURE 5-2 (Continued)

Ten Item Test, 2,000 Subject Case

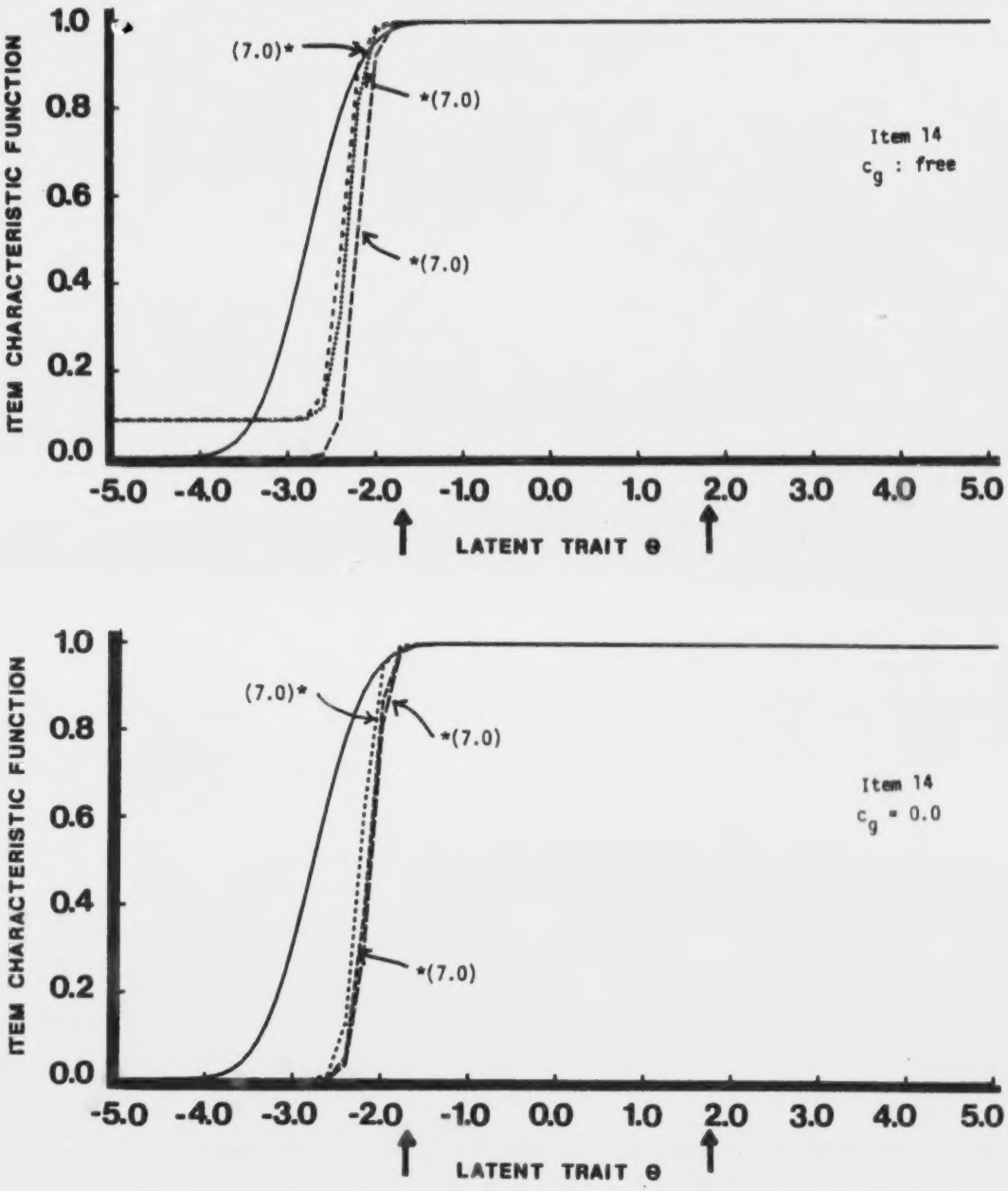


FIGURE 6-1

Theoretical Item Characteristic Function (Solid Line) of Each Item of the Thirty-Five Item Test Following the Normal Ogive Model, And Its Three Estimated Item Characteristic Functions Following the Three-Parameter Logistic Model Using LOGIST 5 , Which Are Based upon the Thirty-Five Item Test (Dotted Line), the Forty-Five Item Test (Short Dashed Line) and the Eighty Item Test (Long Dashed Line), Respectively. The Guessing Parameter Is Set Free in the Upper Graph, And Set Equal to Zero in the Lower Graph.

500 Subject Case.

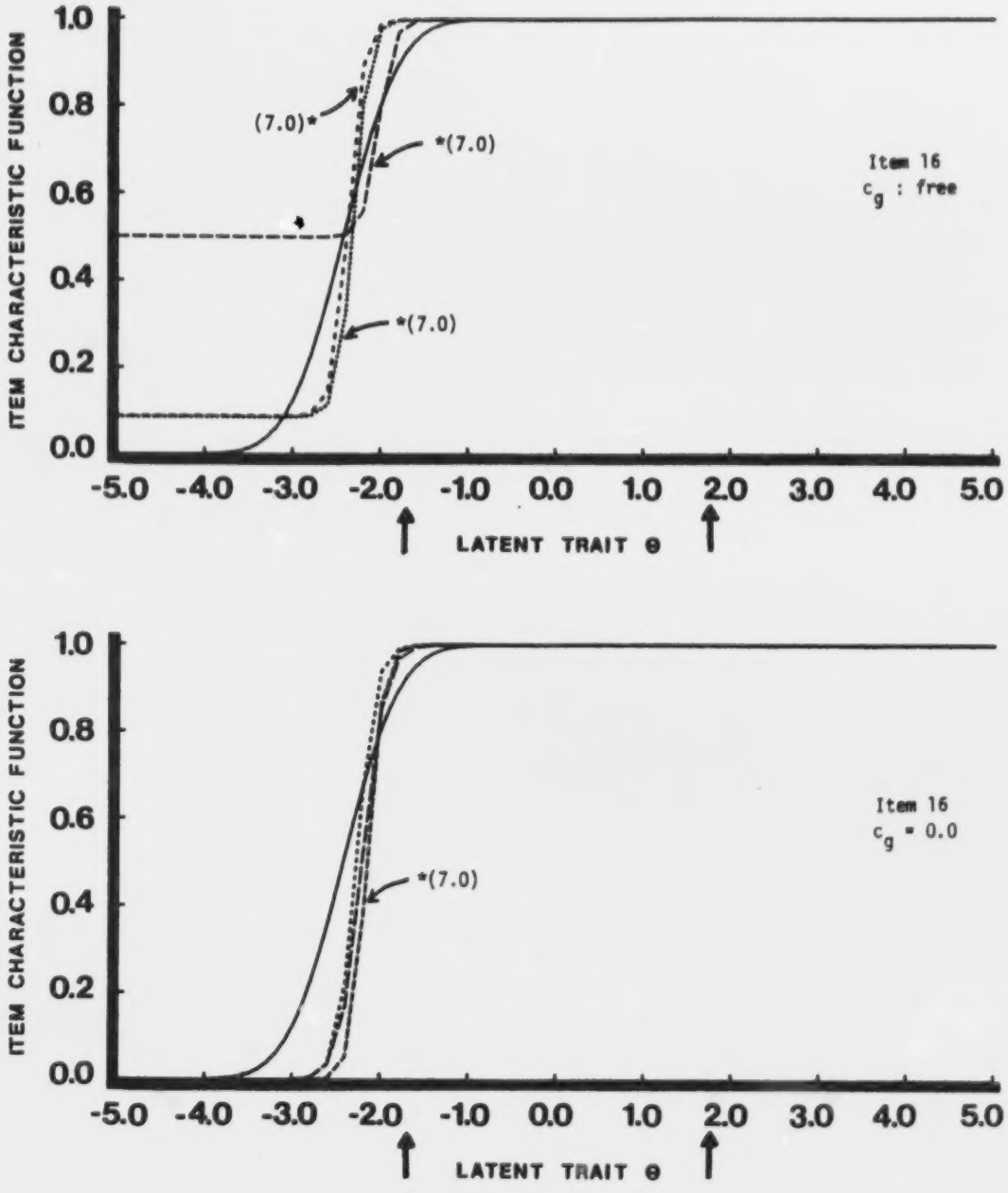


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

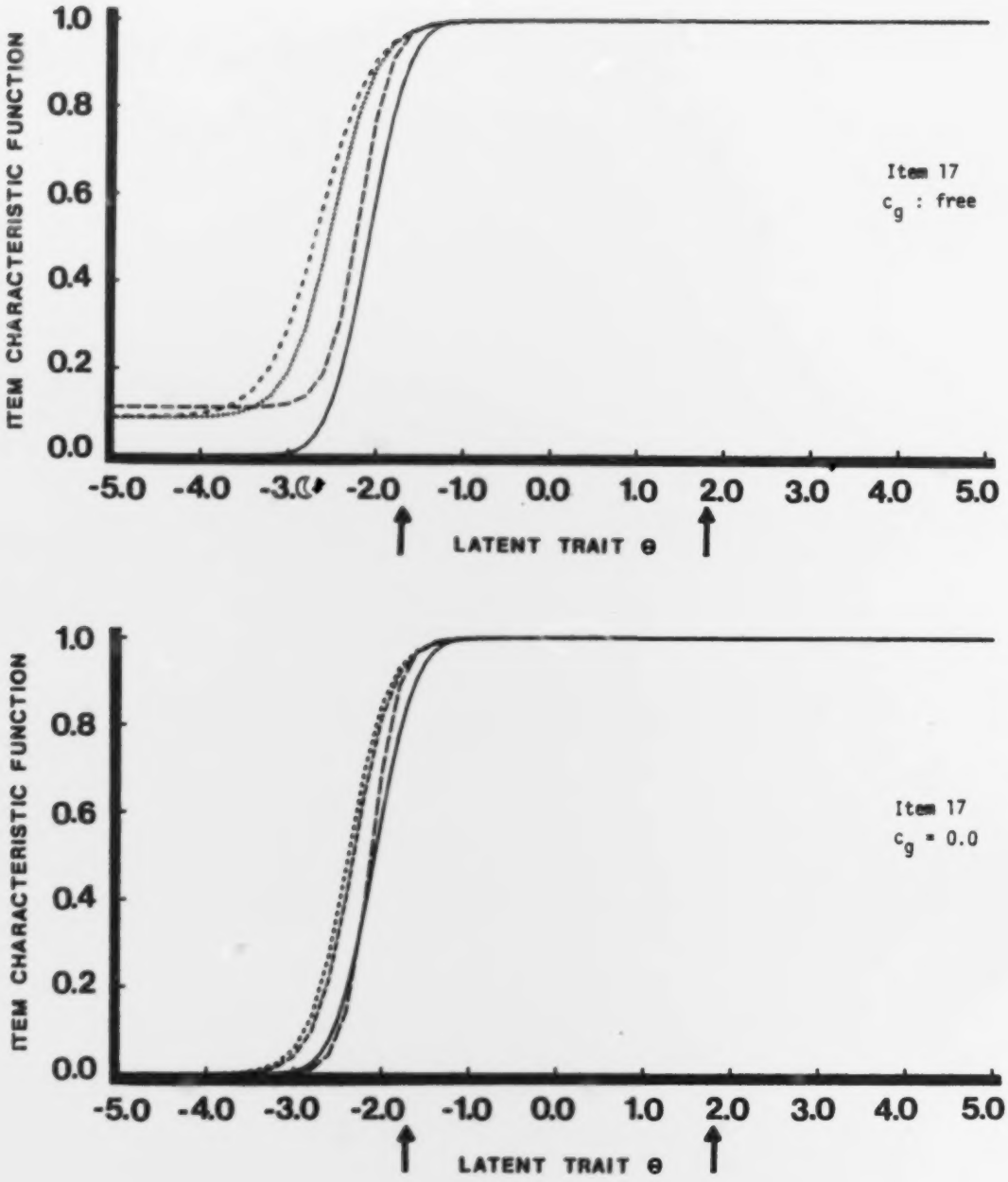


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

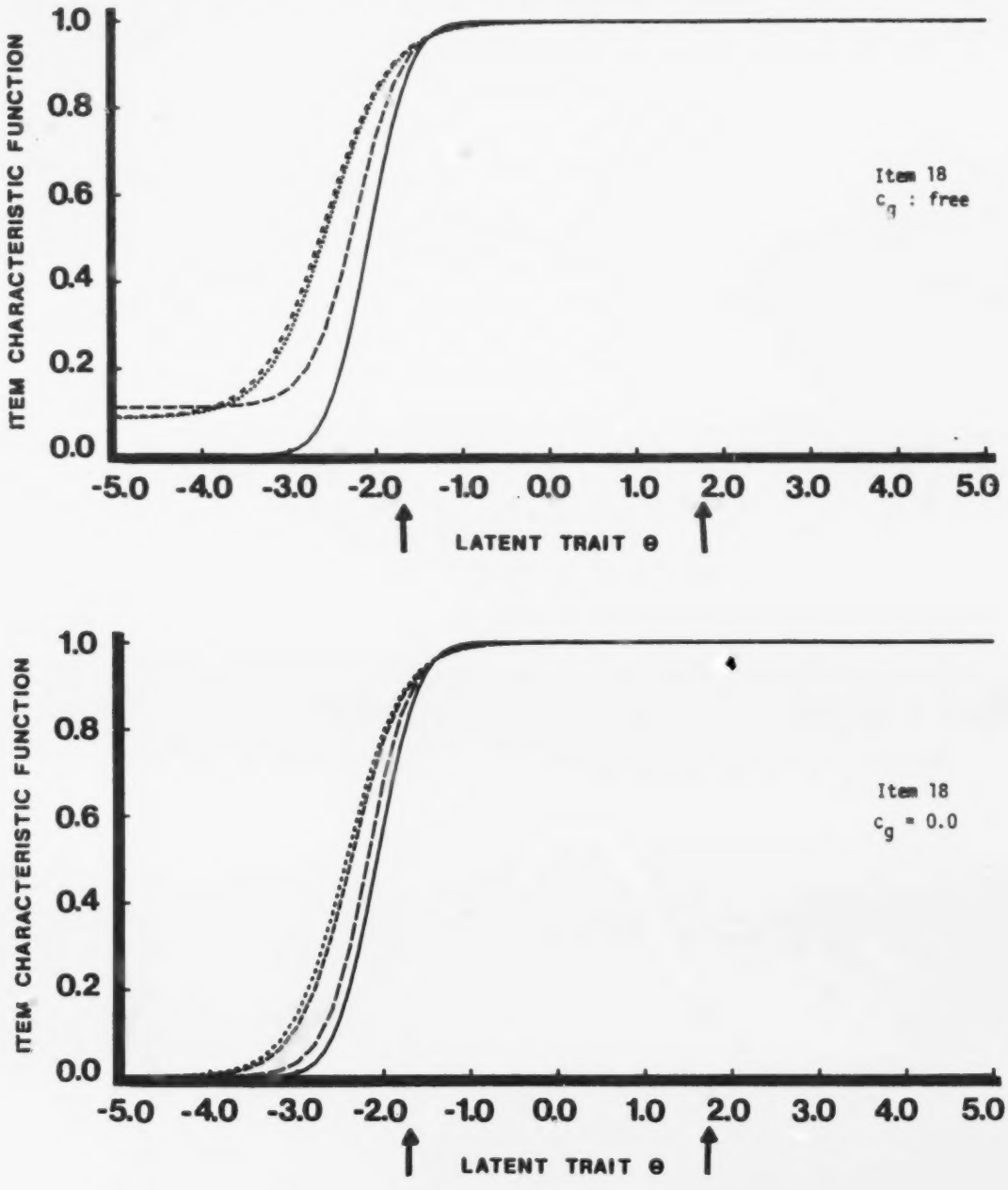


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

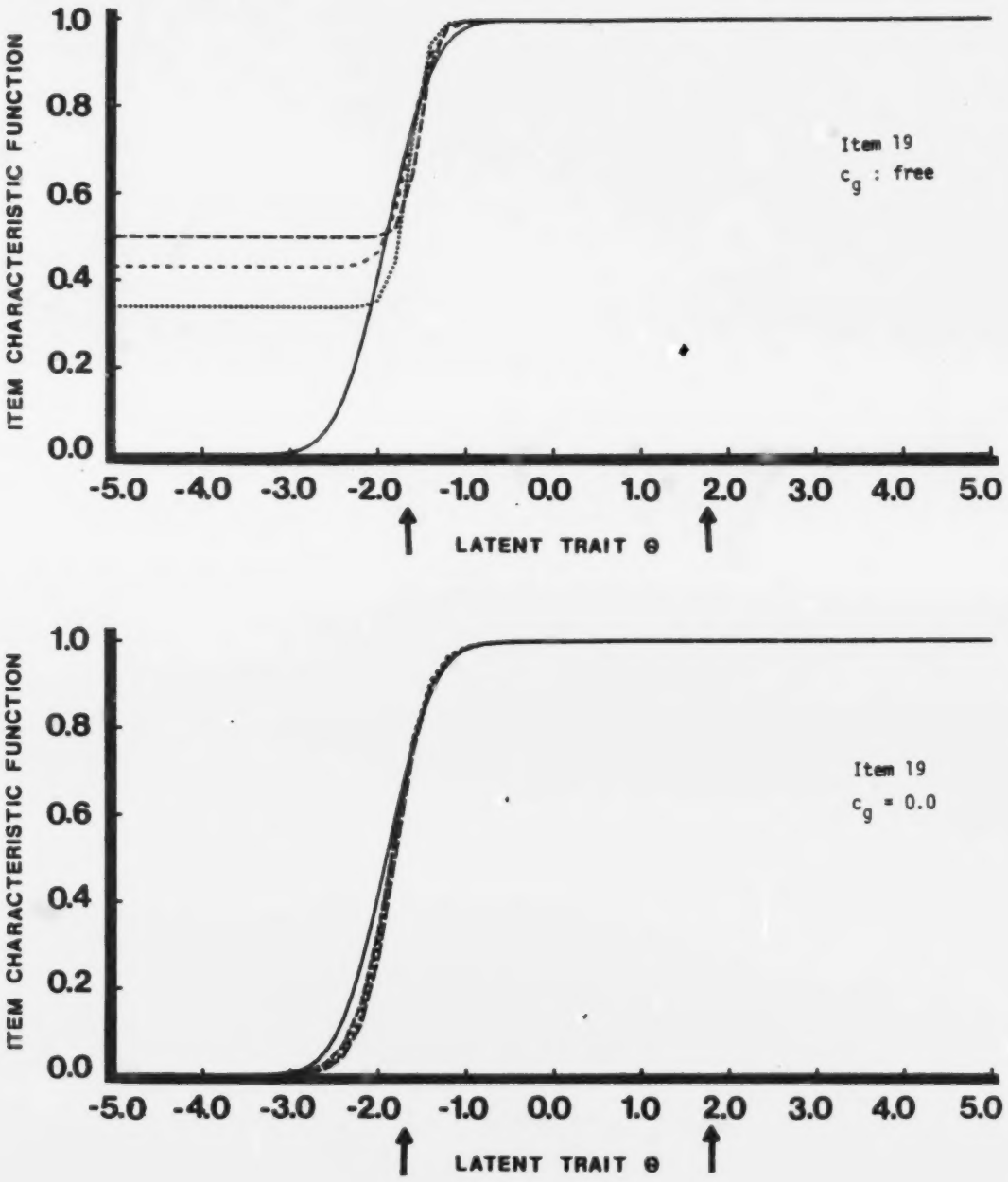


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

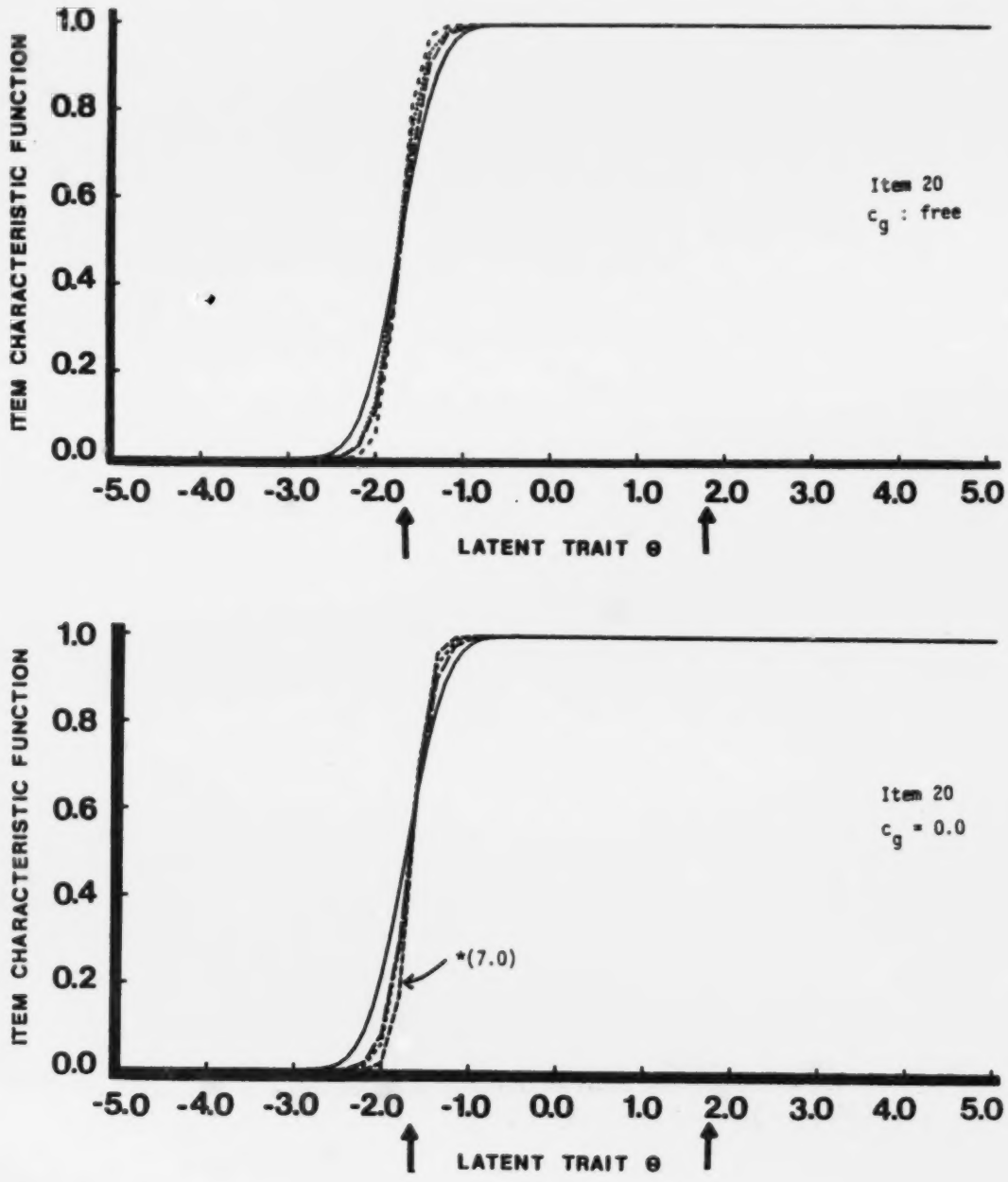


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

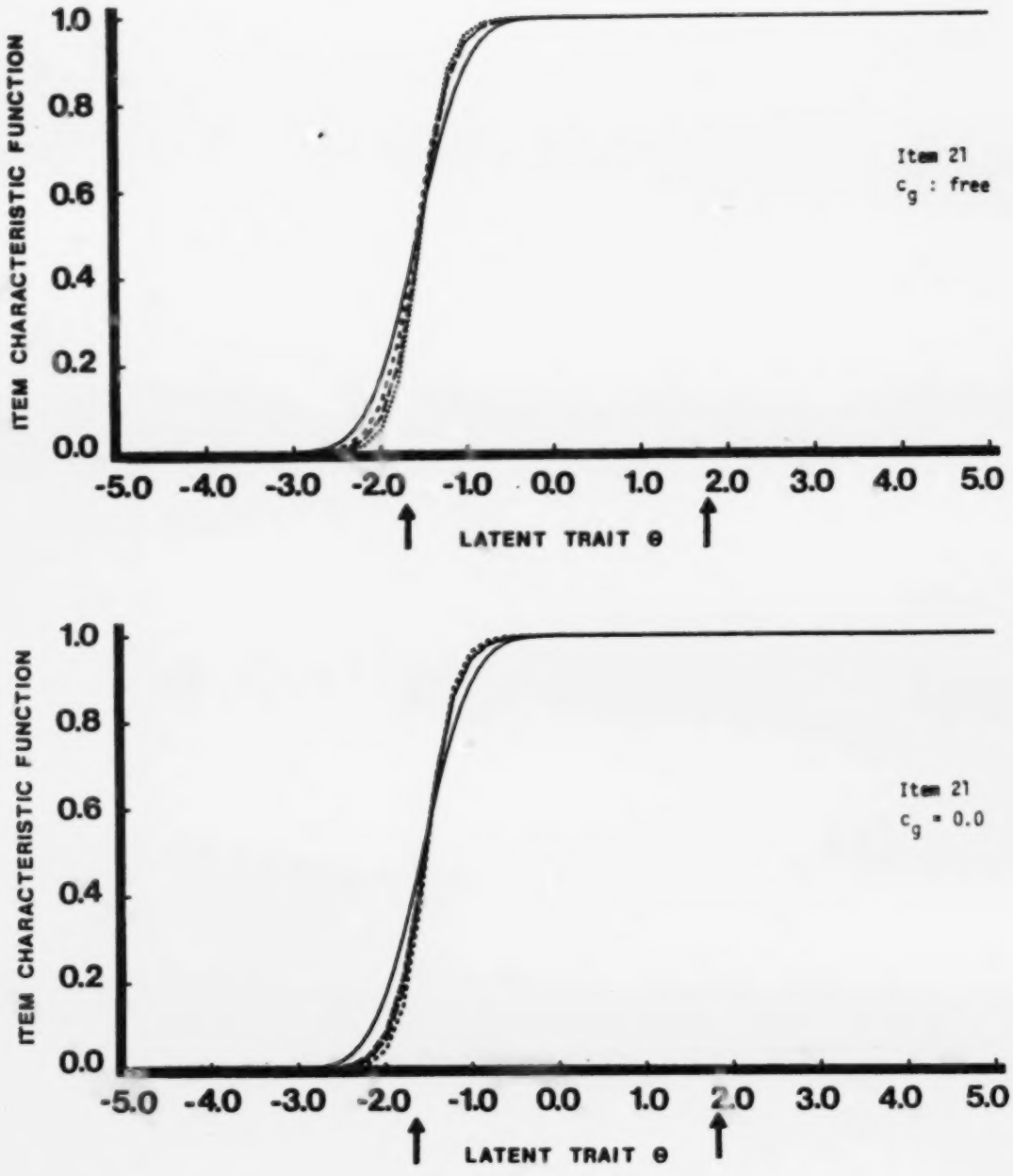
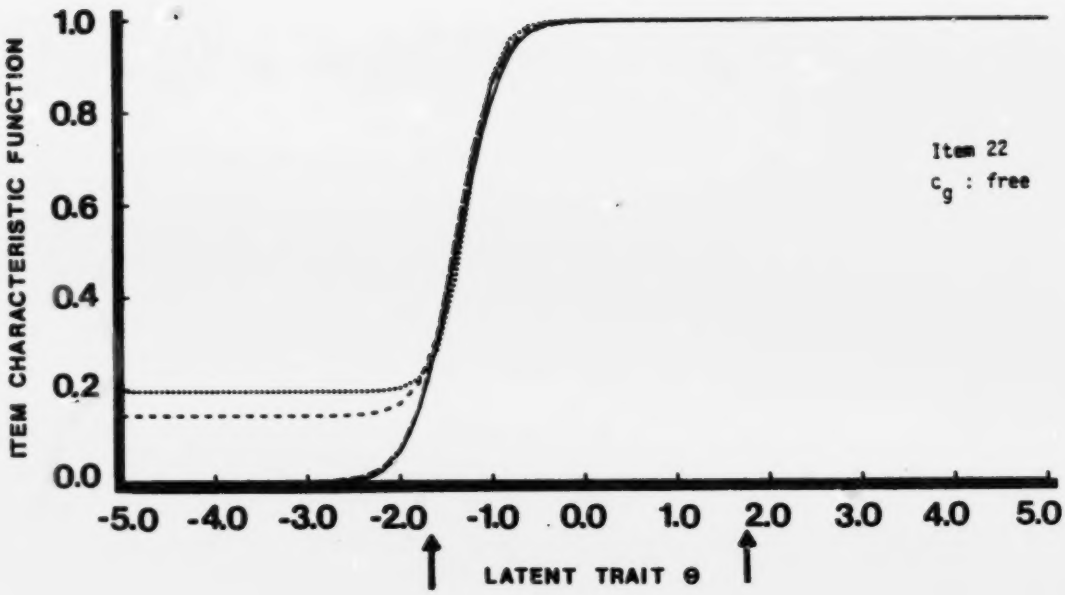


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case



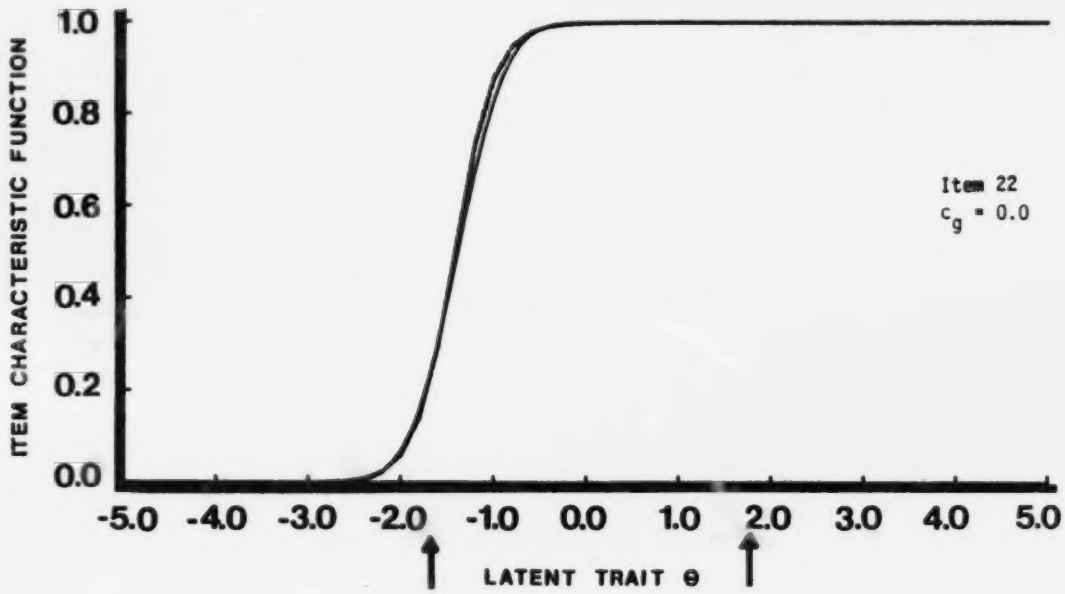


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

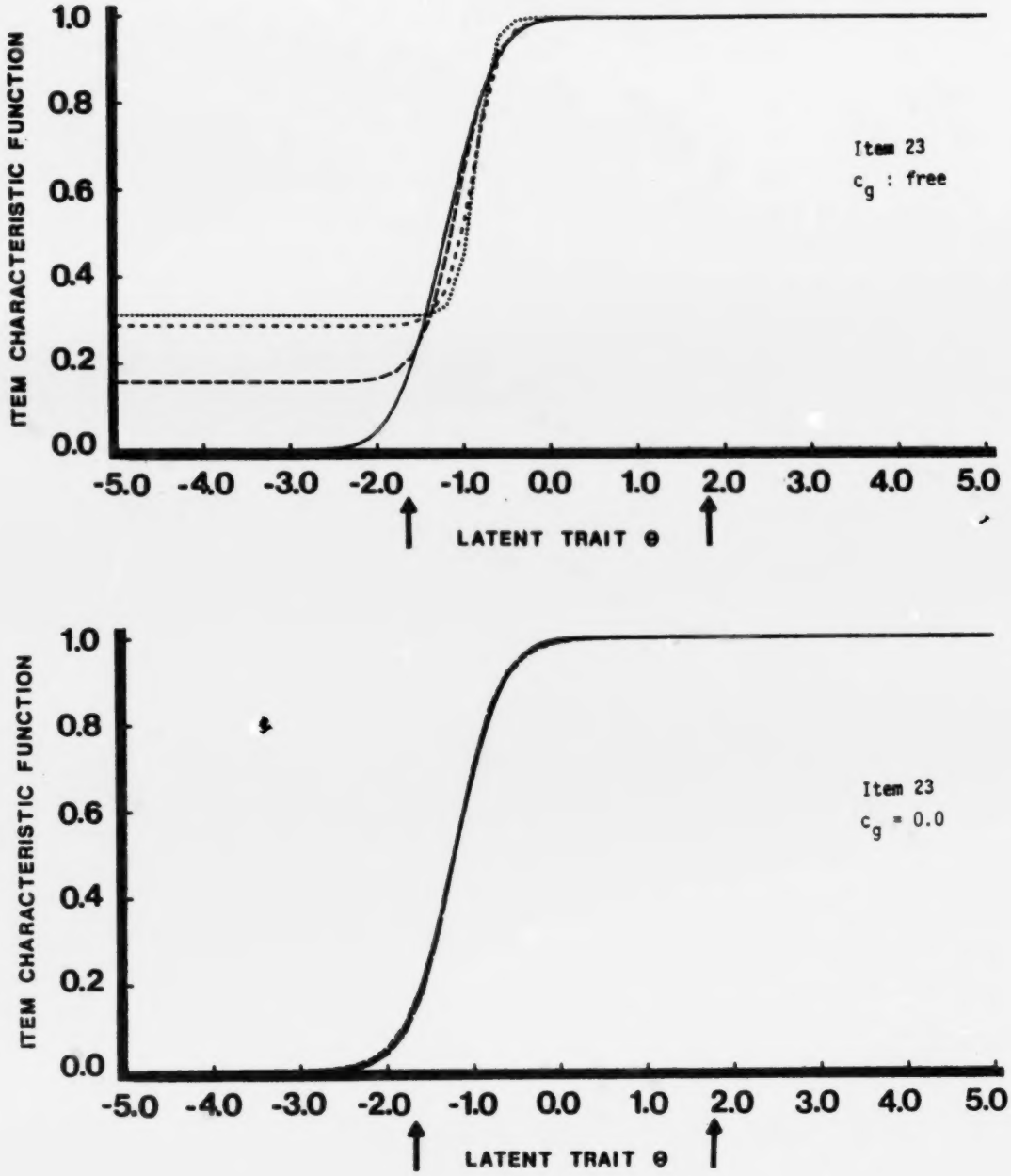


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

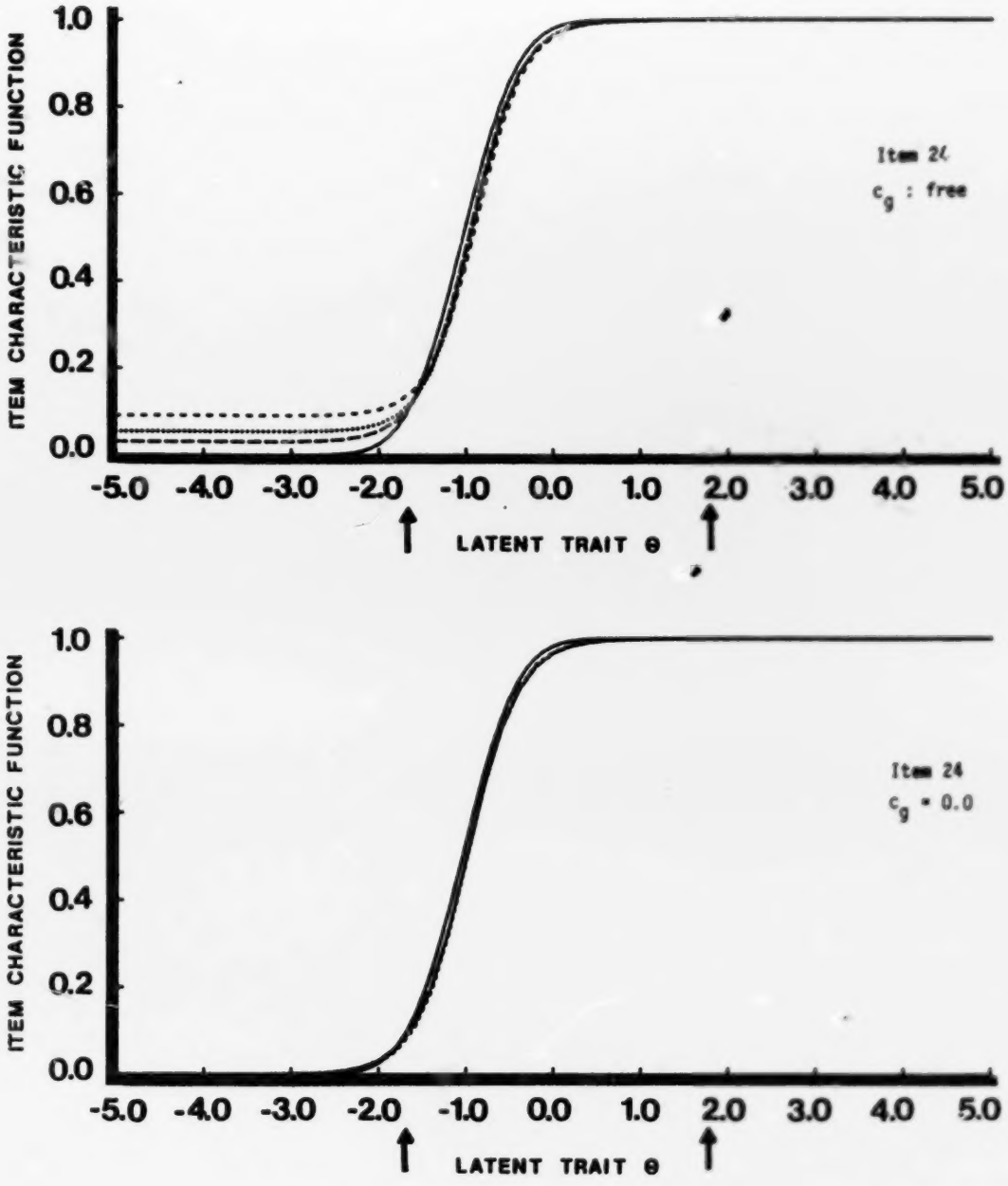


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

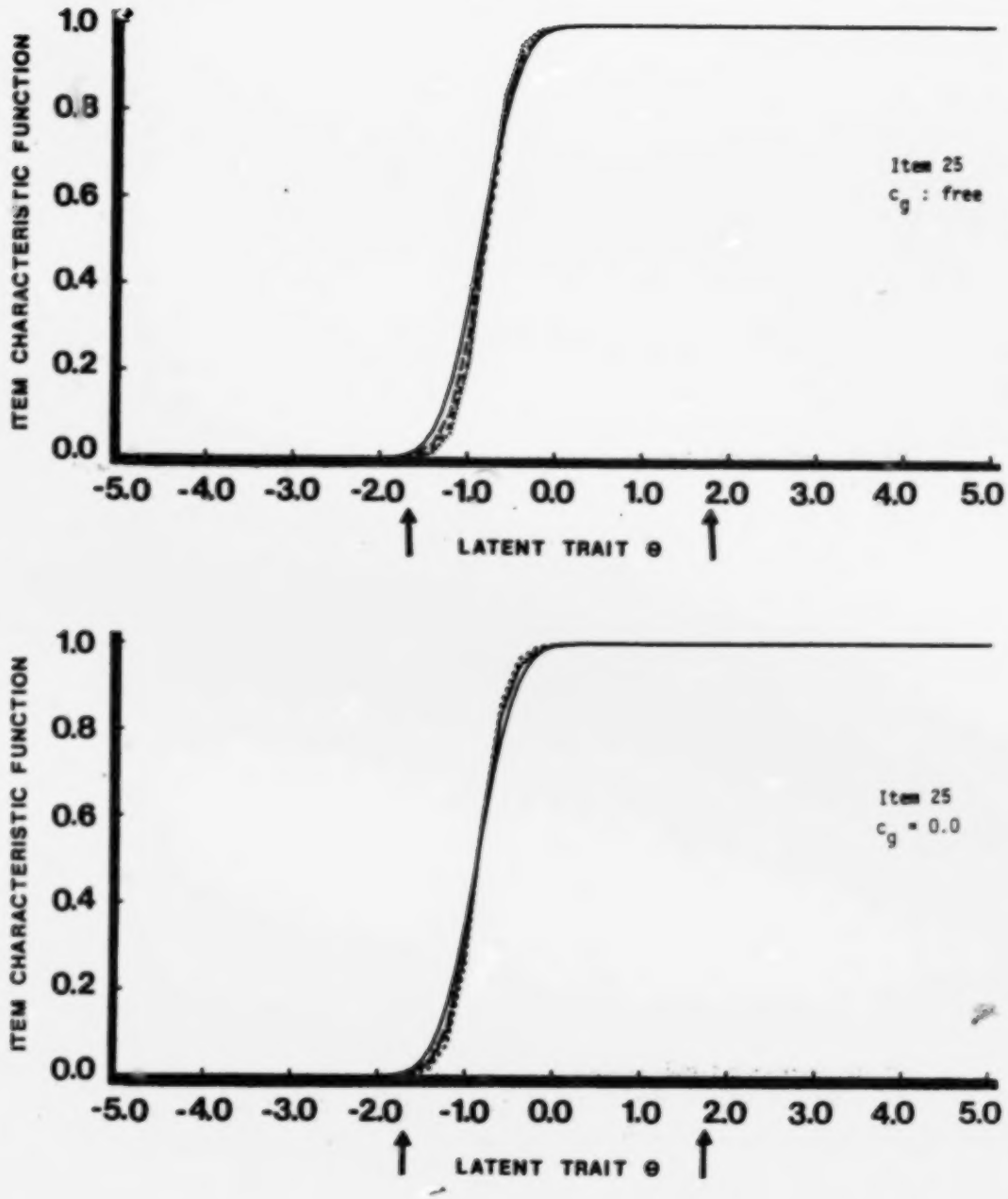


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

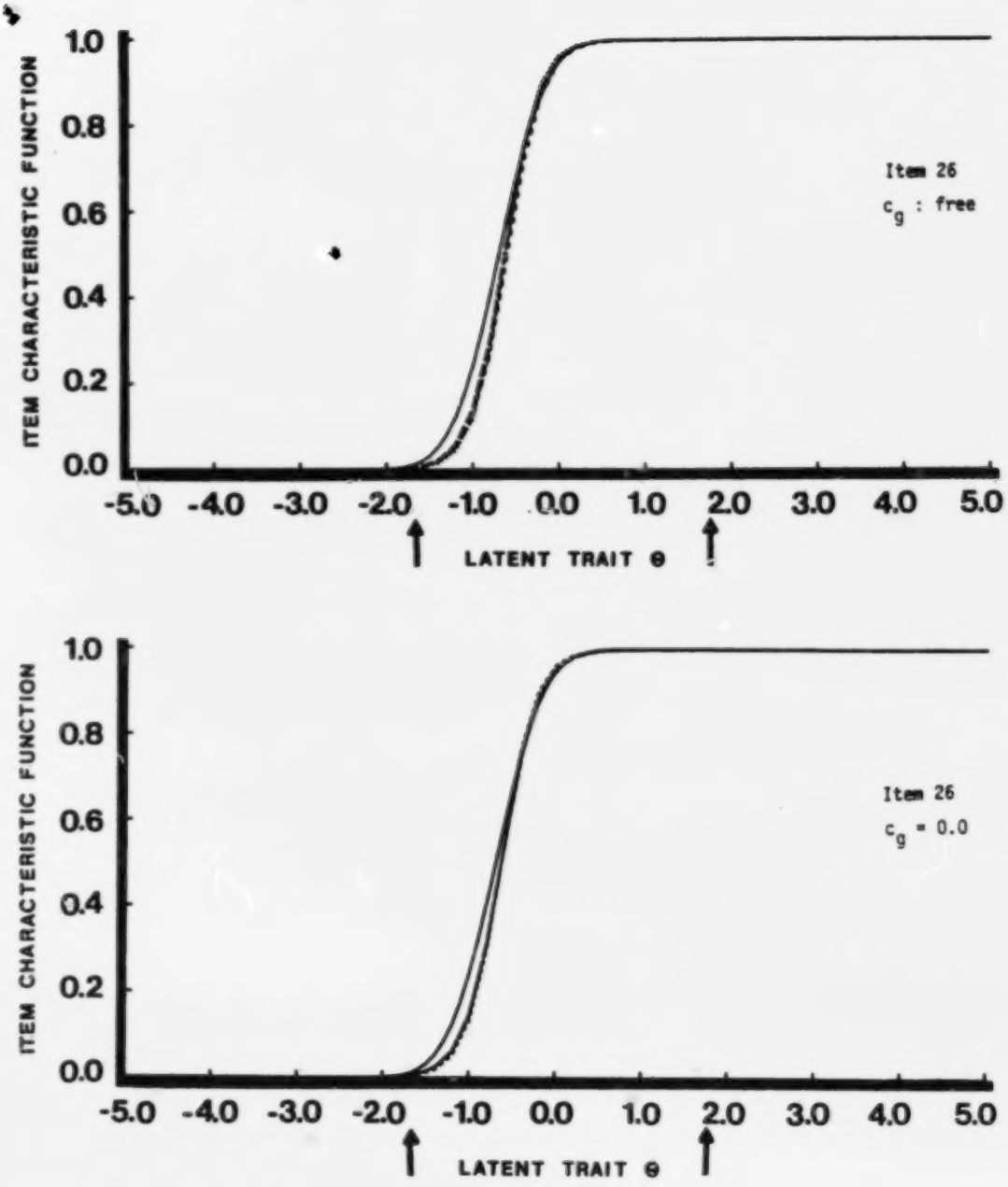


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

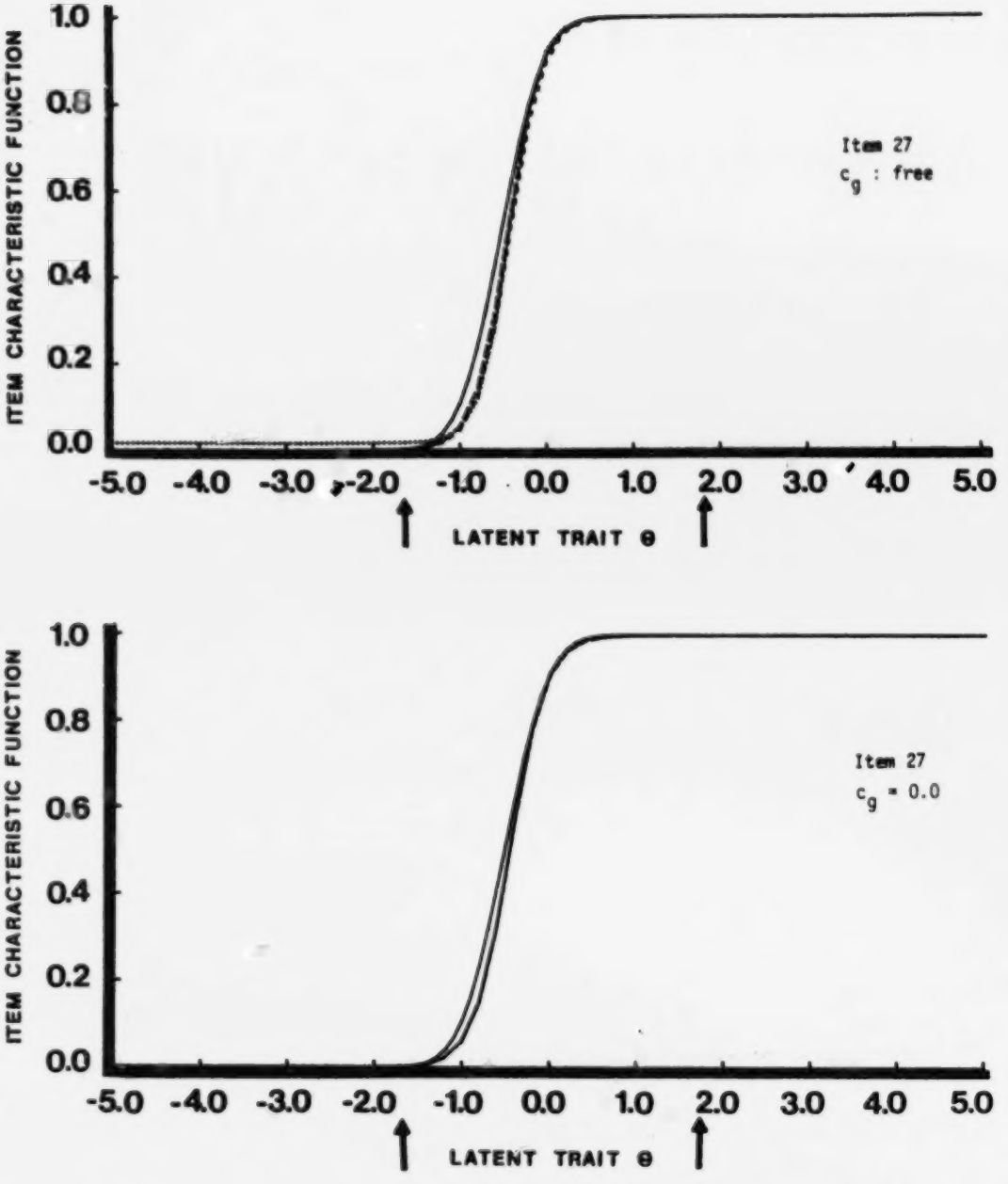


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

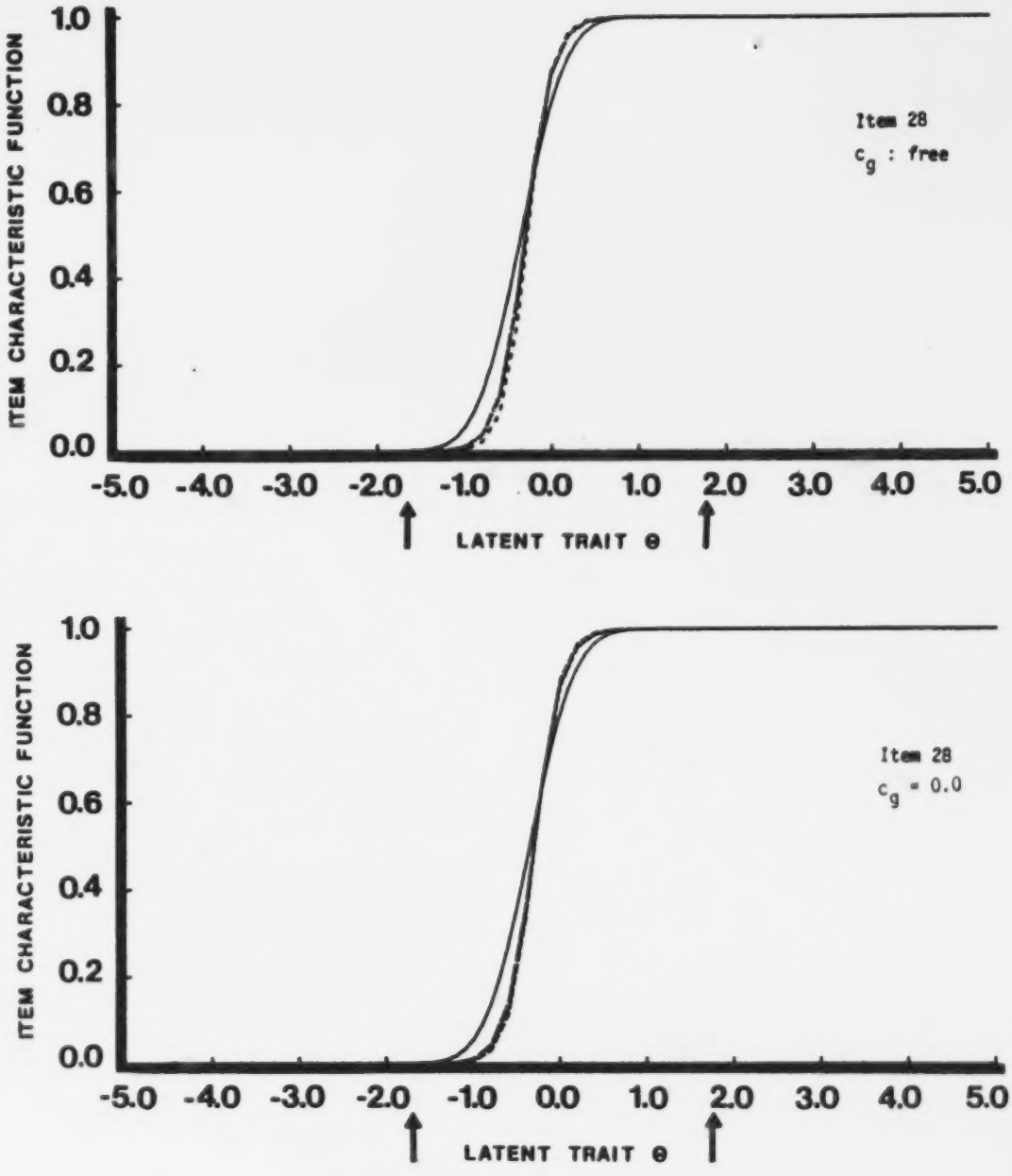
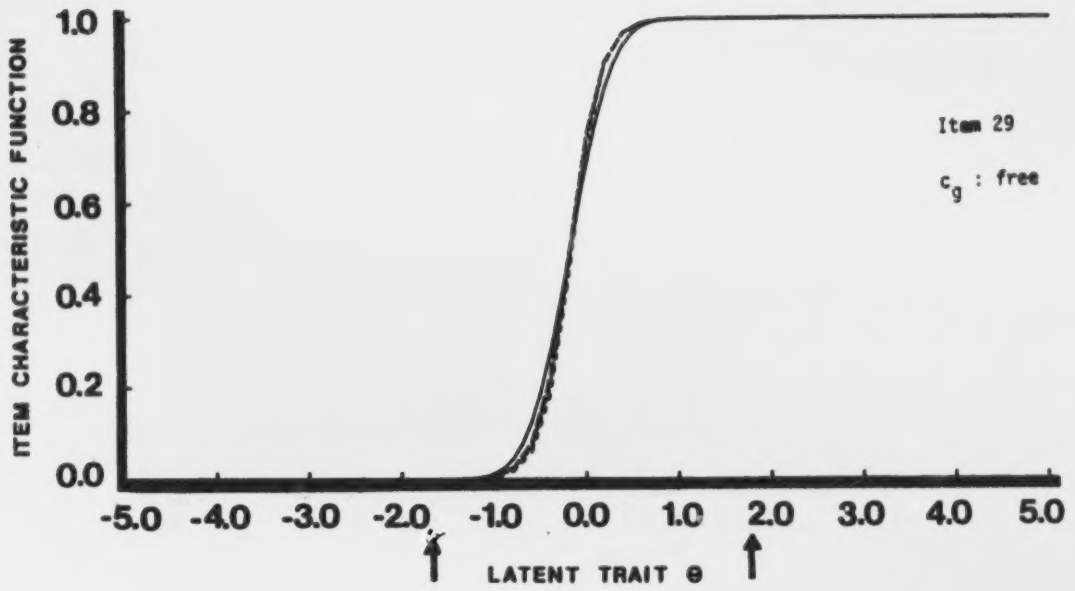


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case



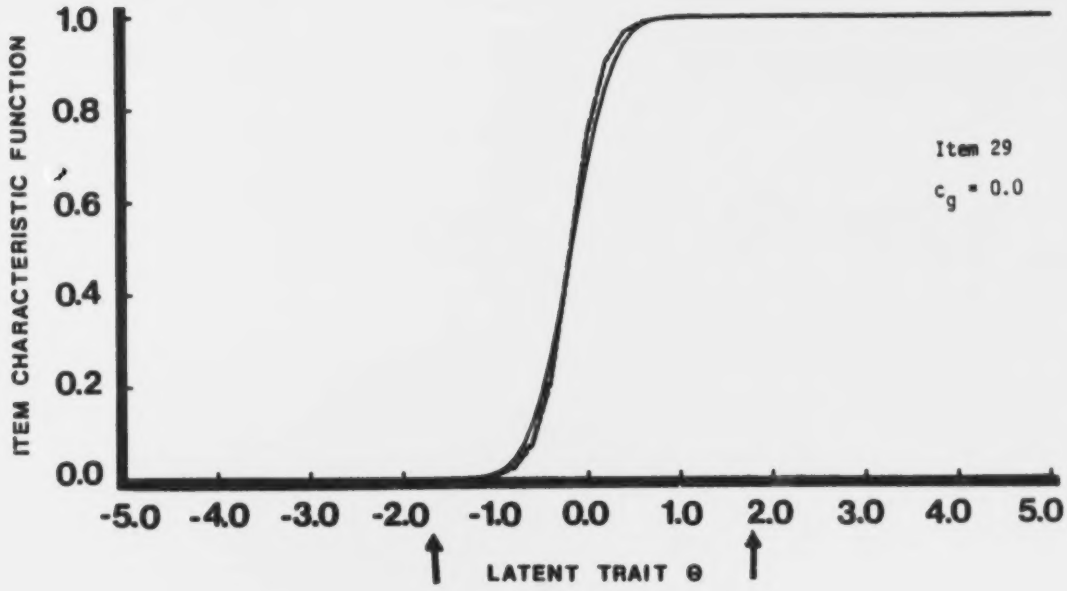


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

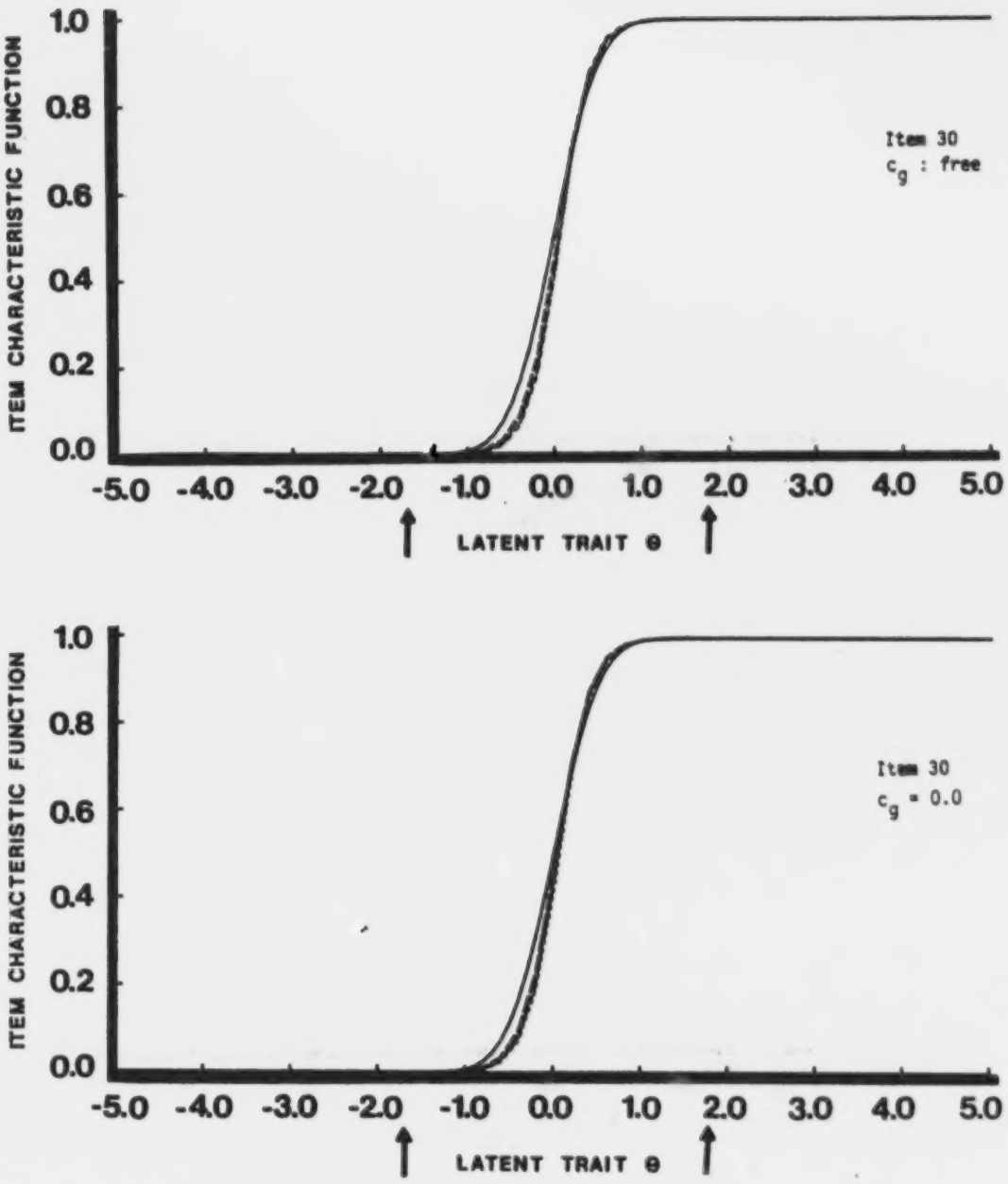
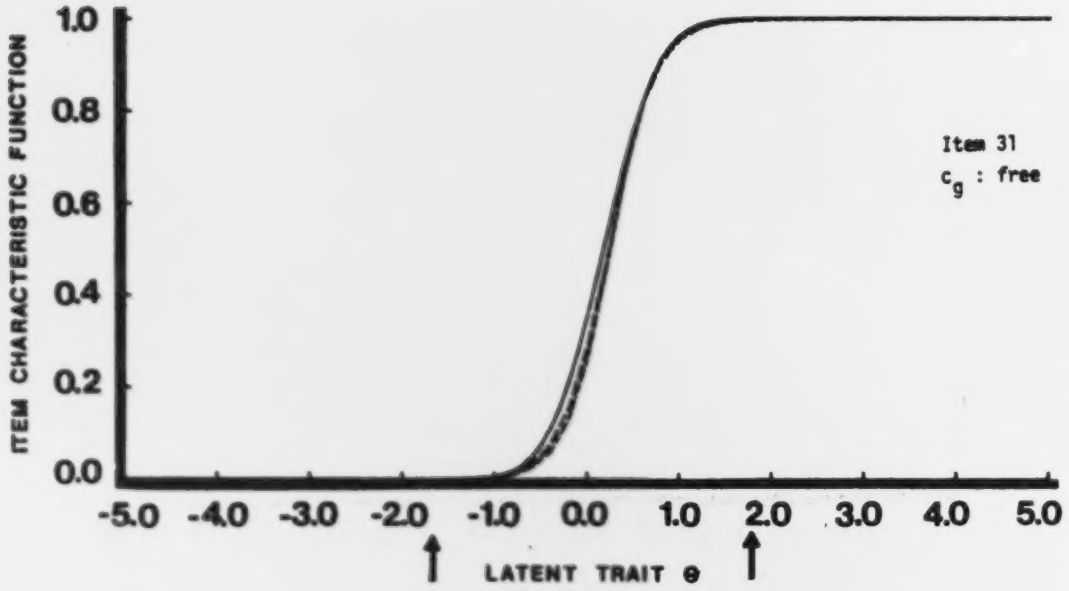


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case



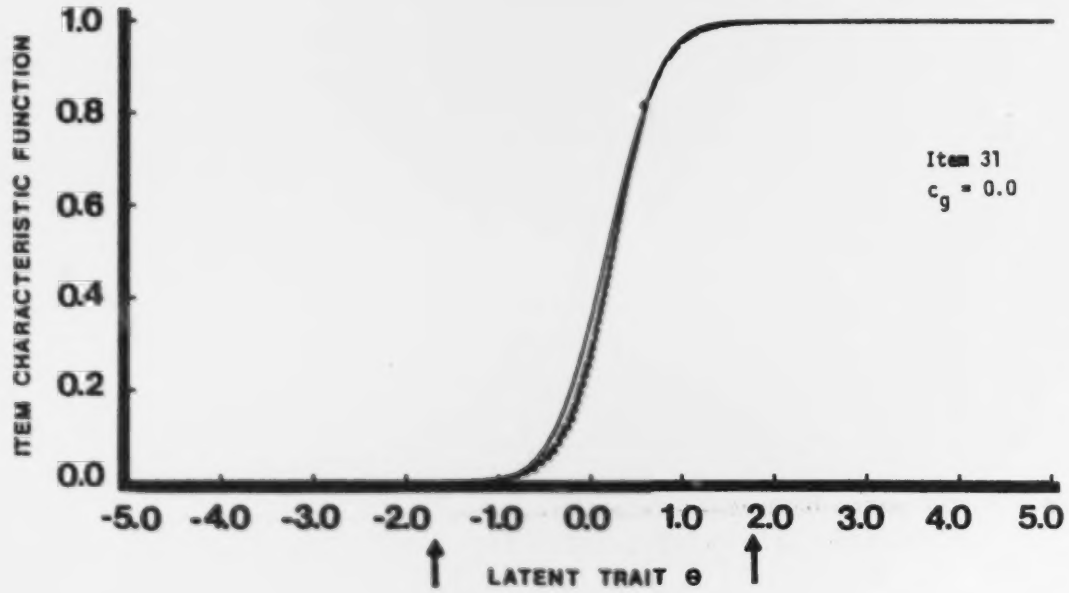
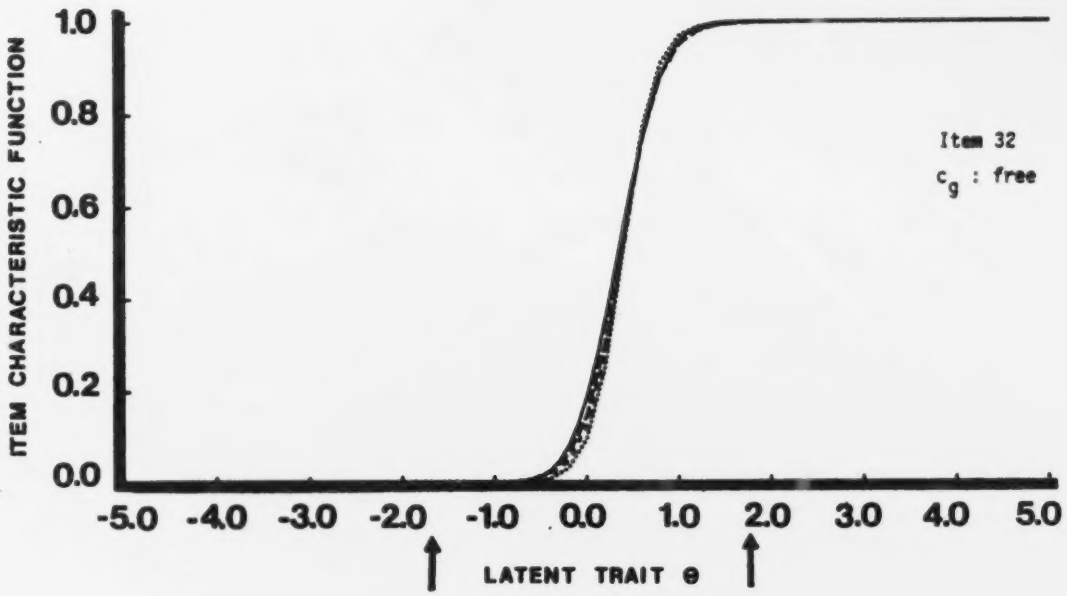


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case



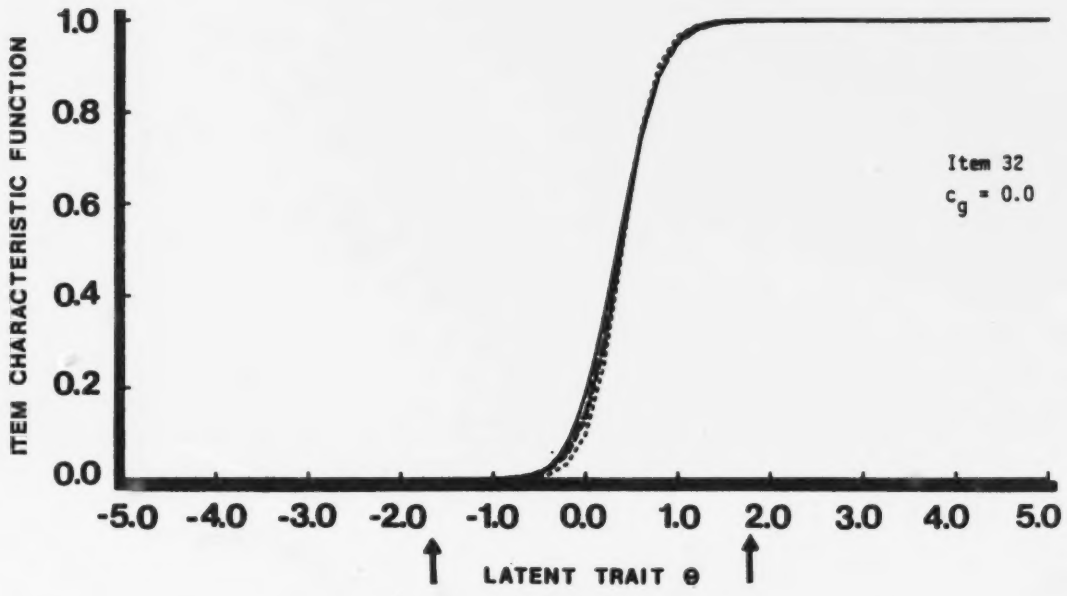
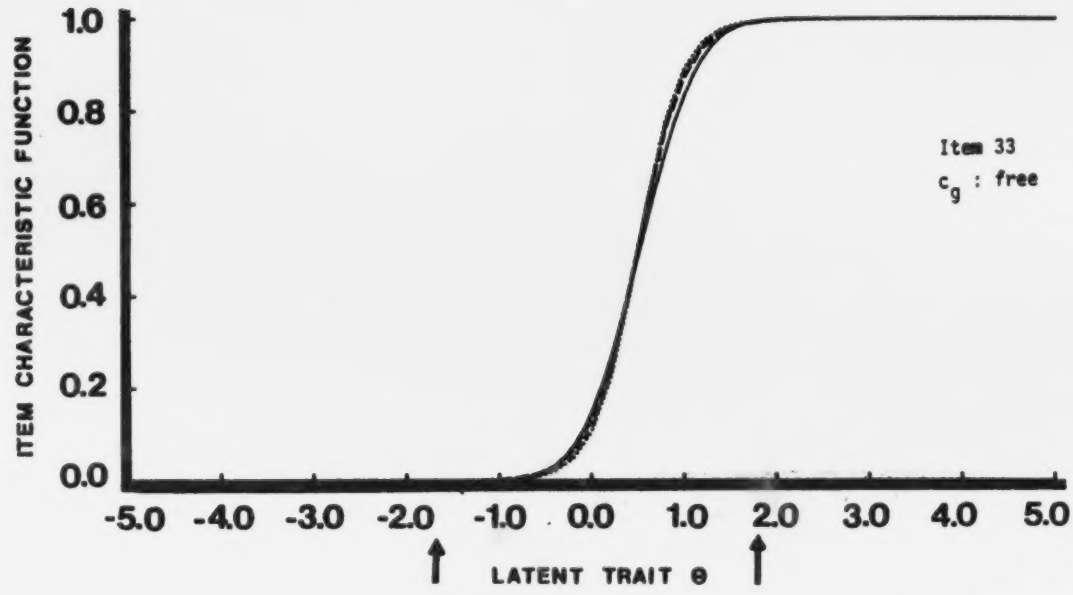


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case



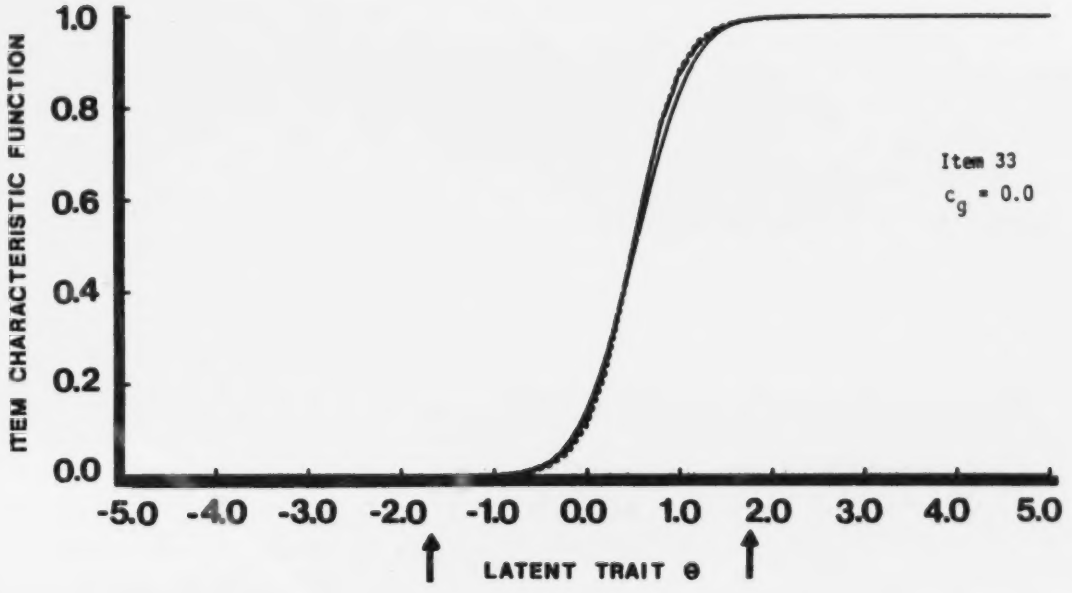


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

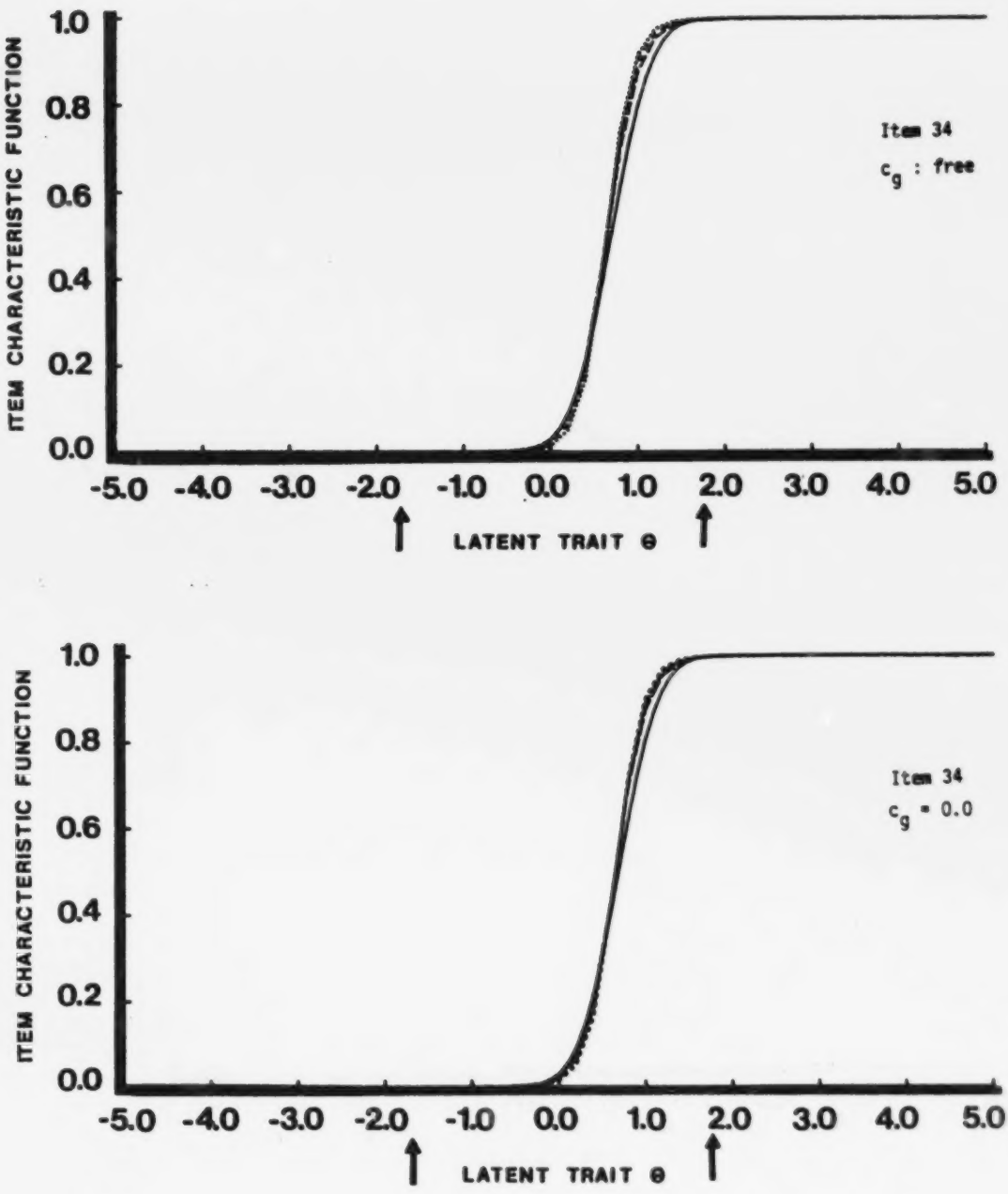
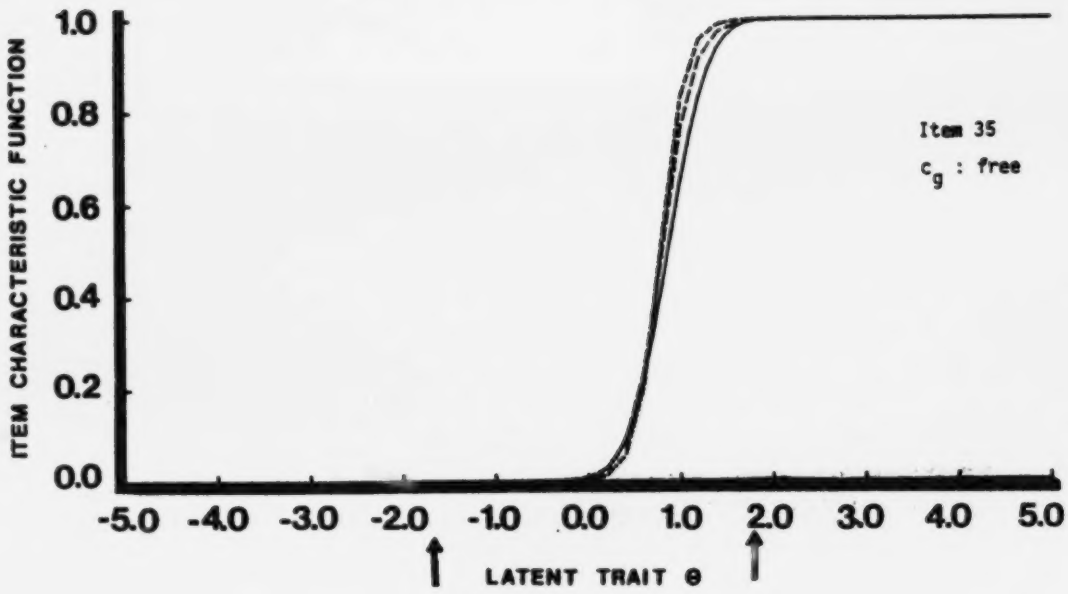


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case



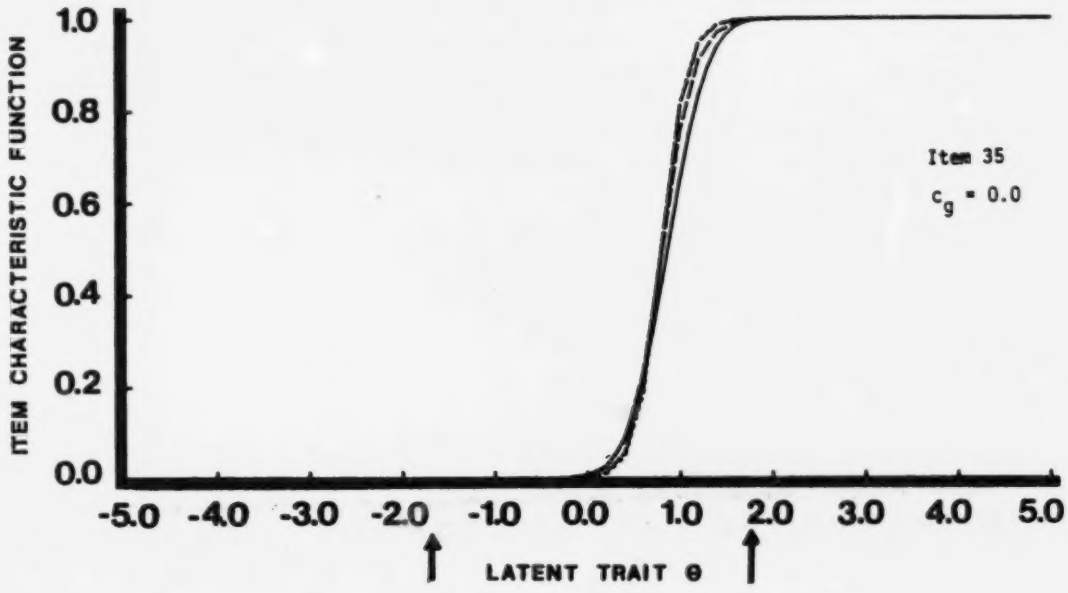
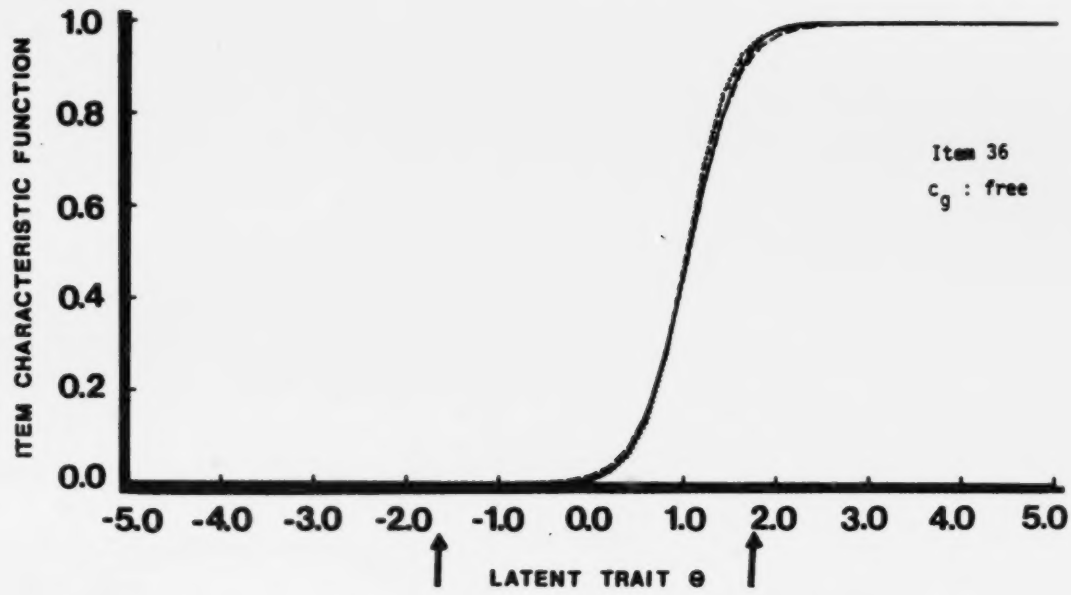


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case



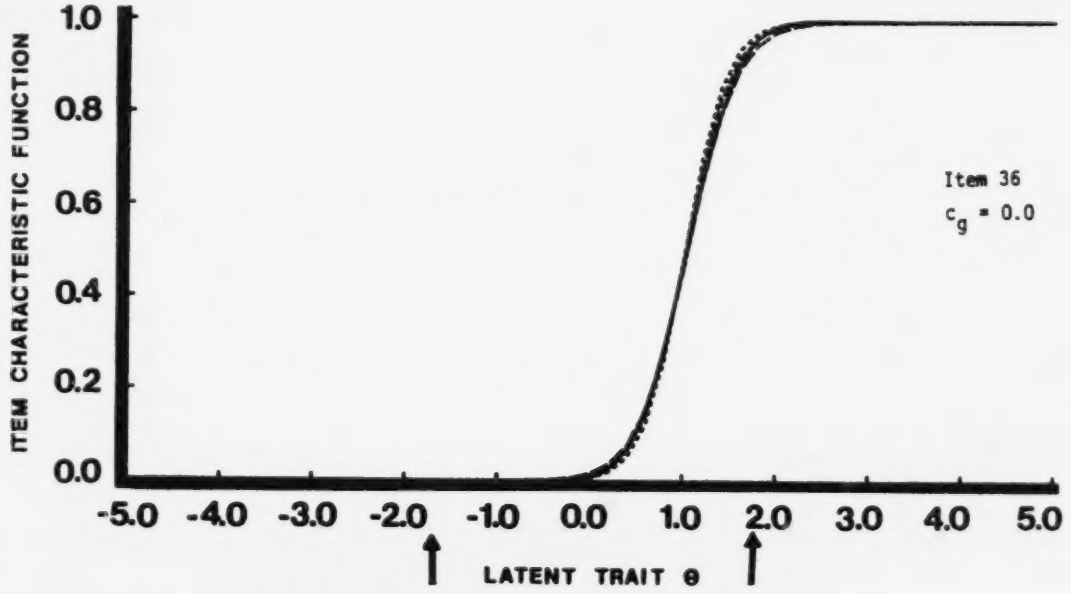
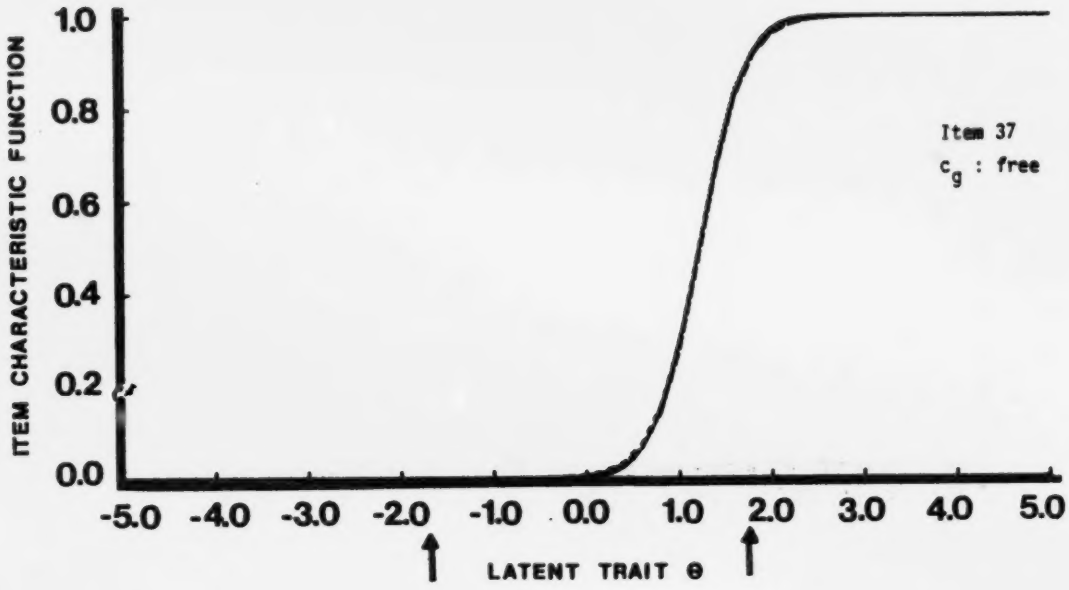


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case



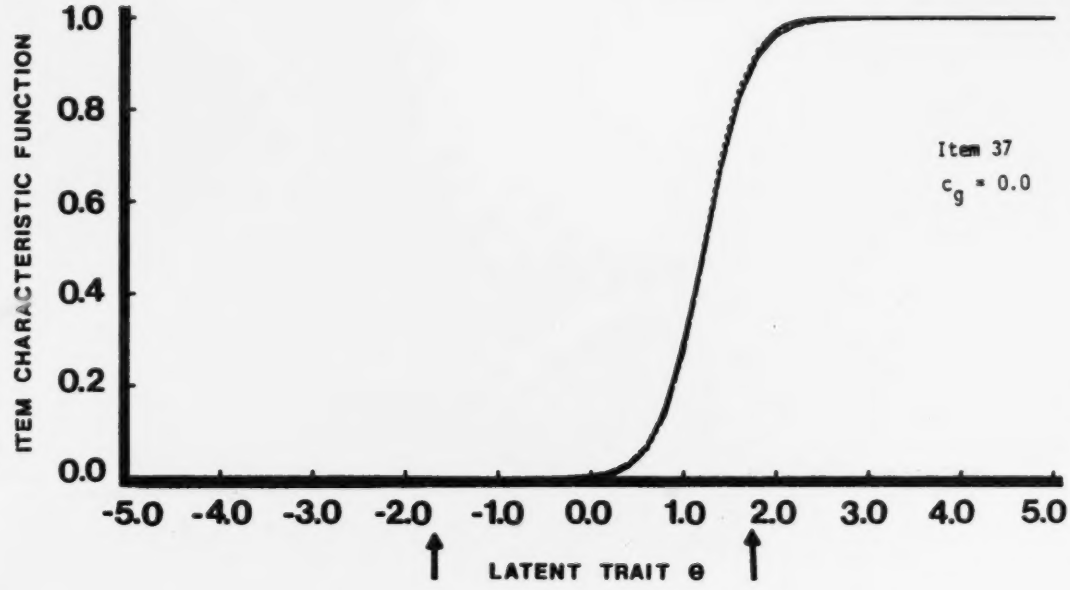
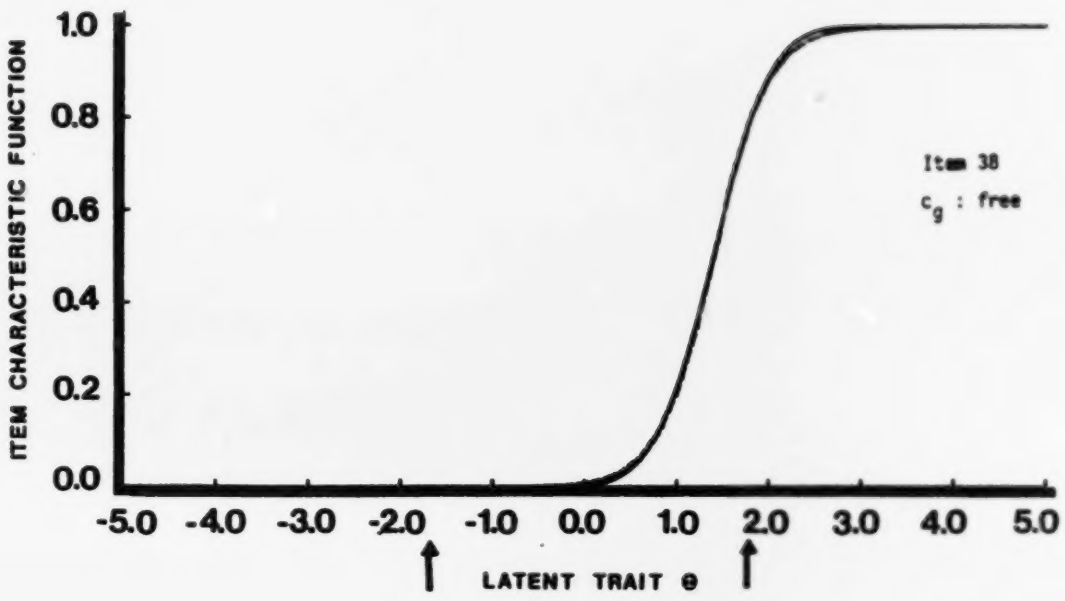


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case



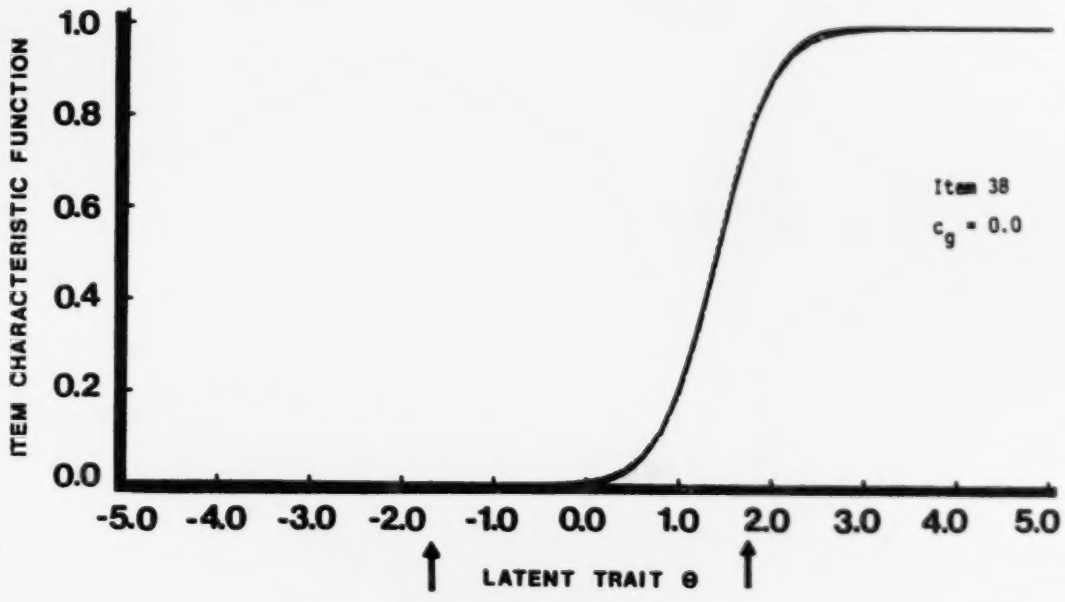
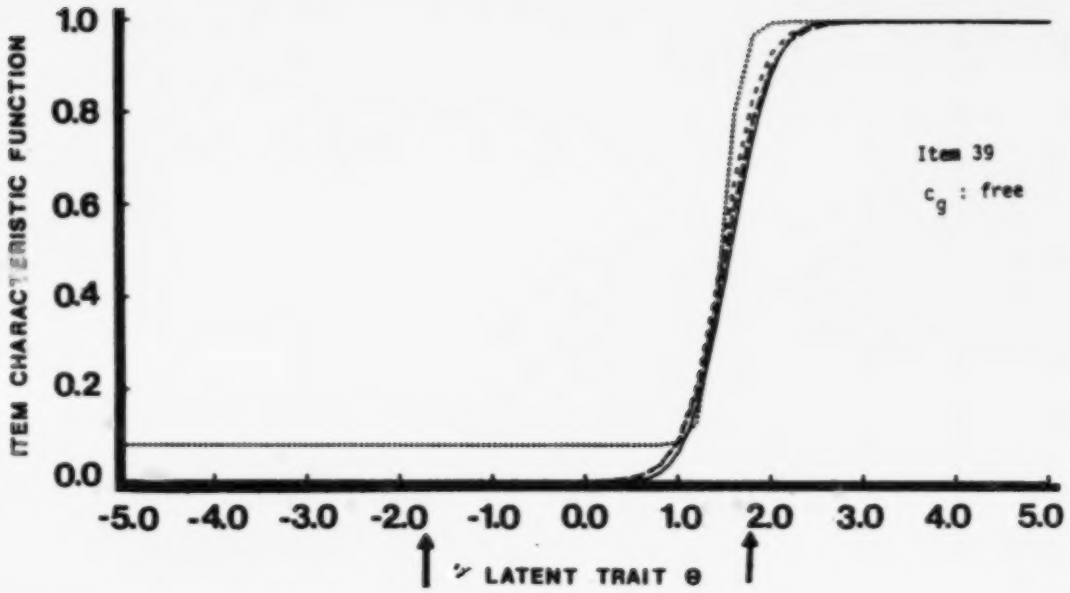


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case



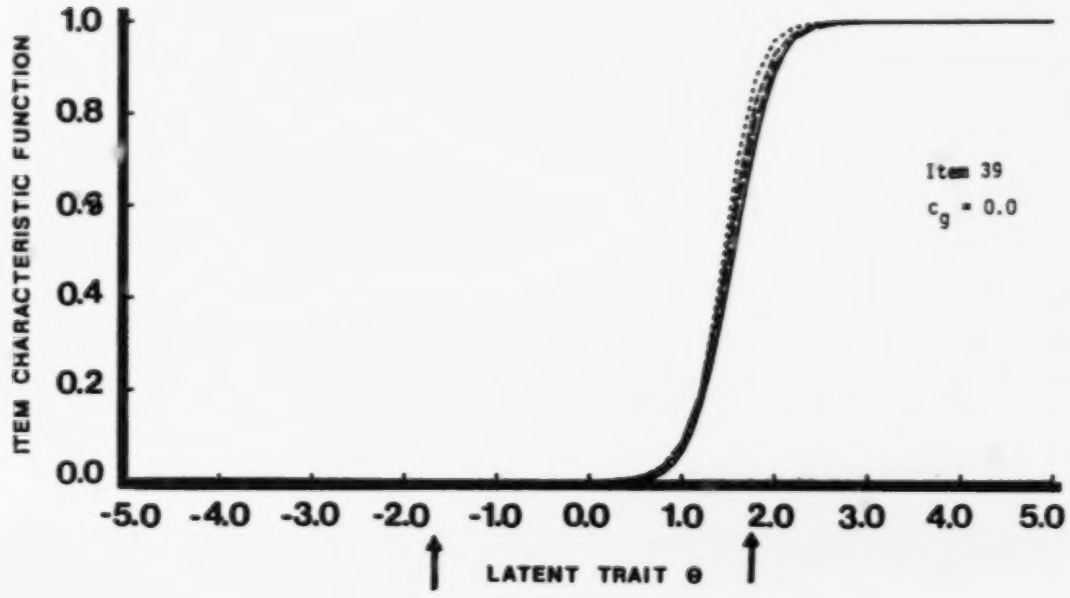


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

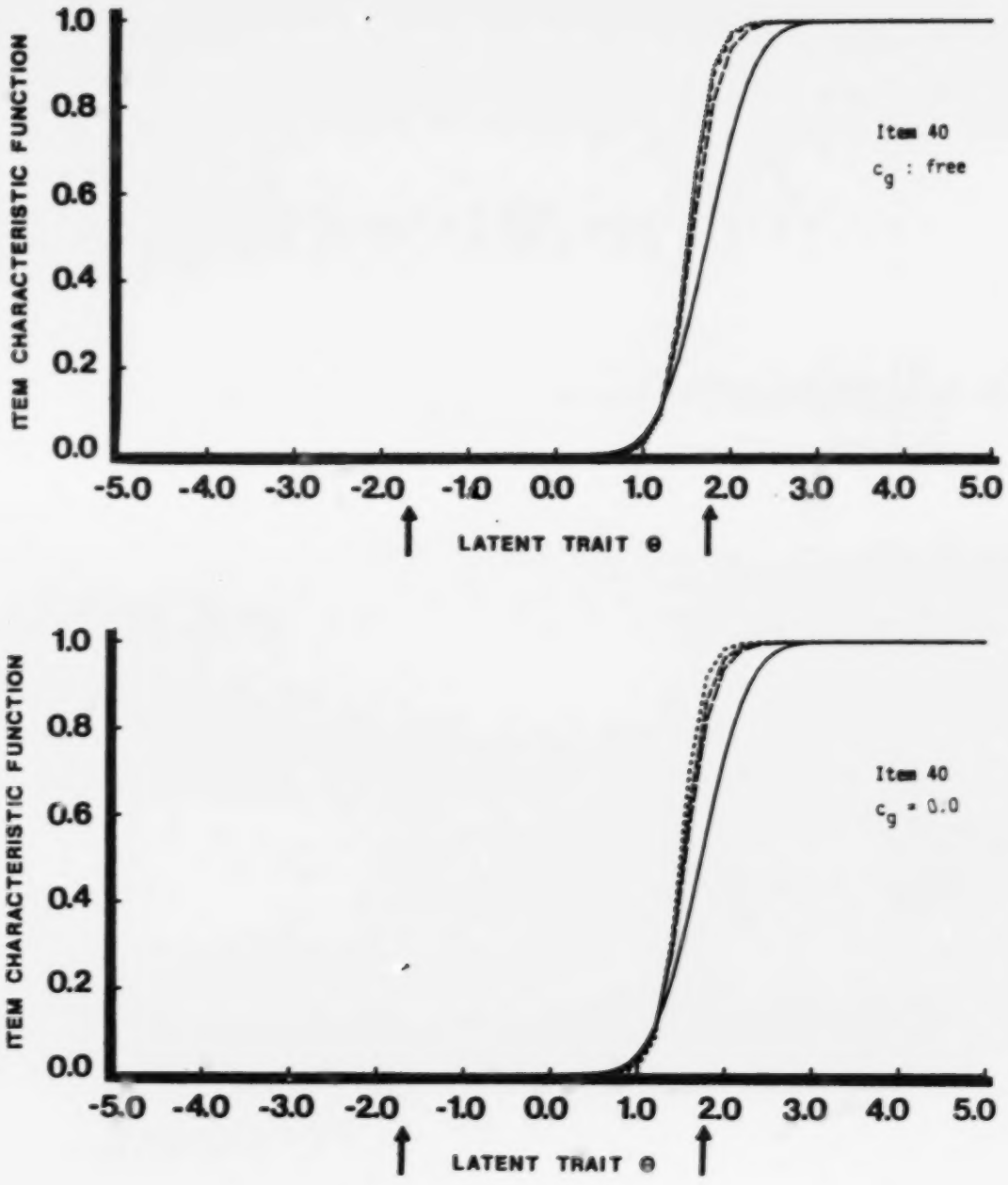
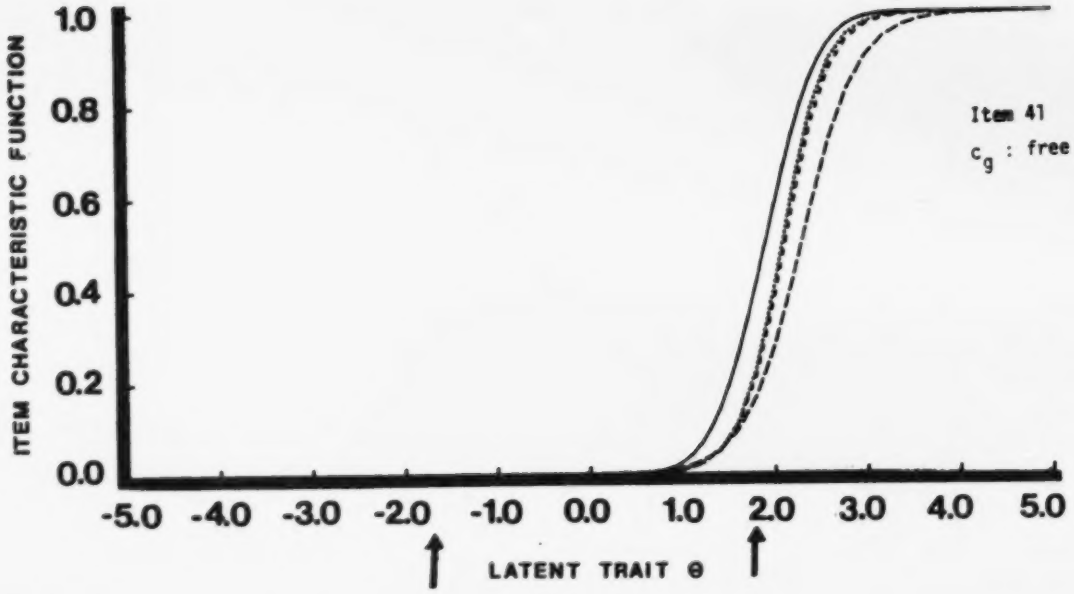


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case



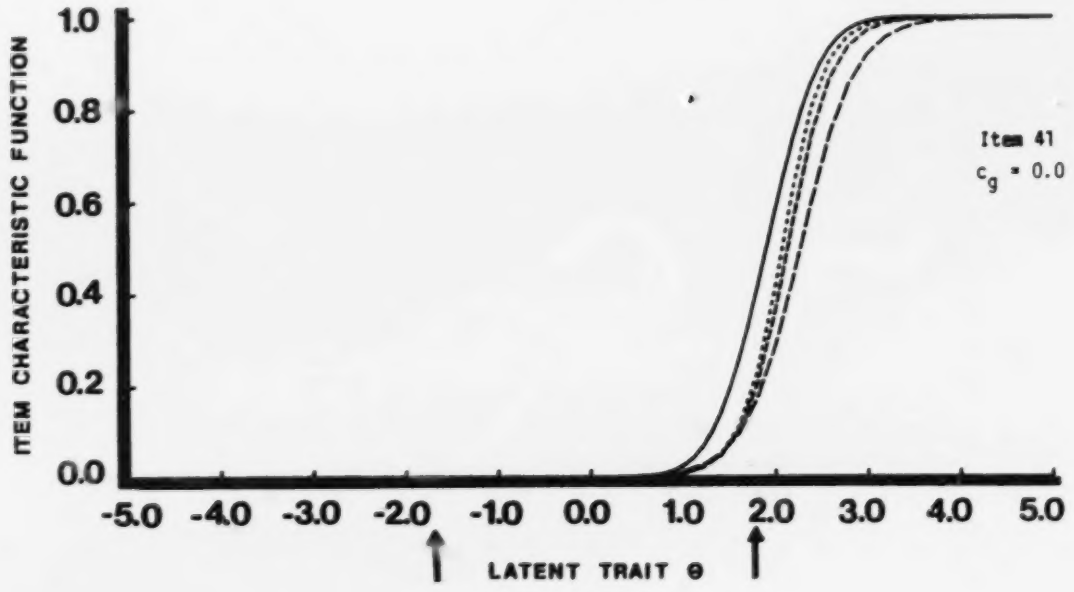


FIGURE 6-1 (Continued)

Thirty-Five Item Test, 500 Subject Case

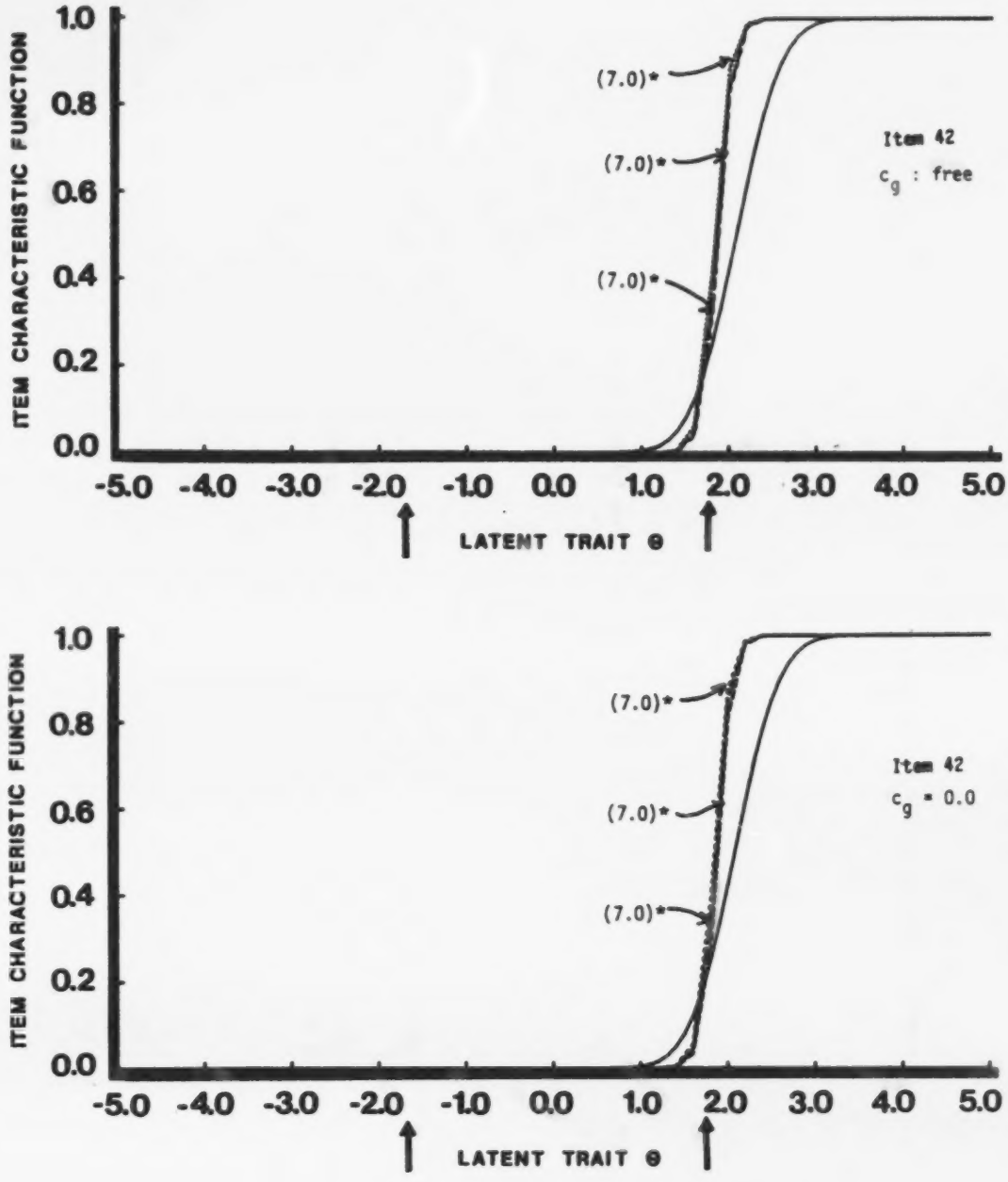


FIGURE 6-1 (Continued)

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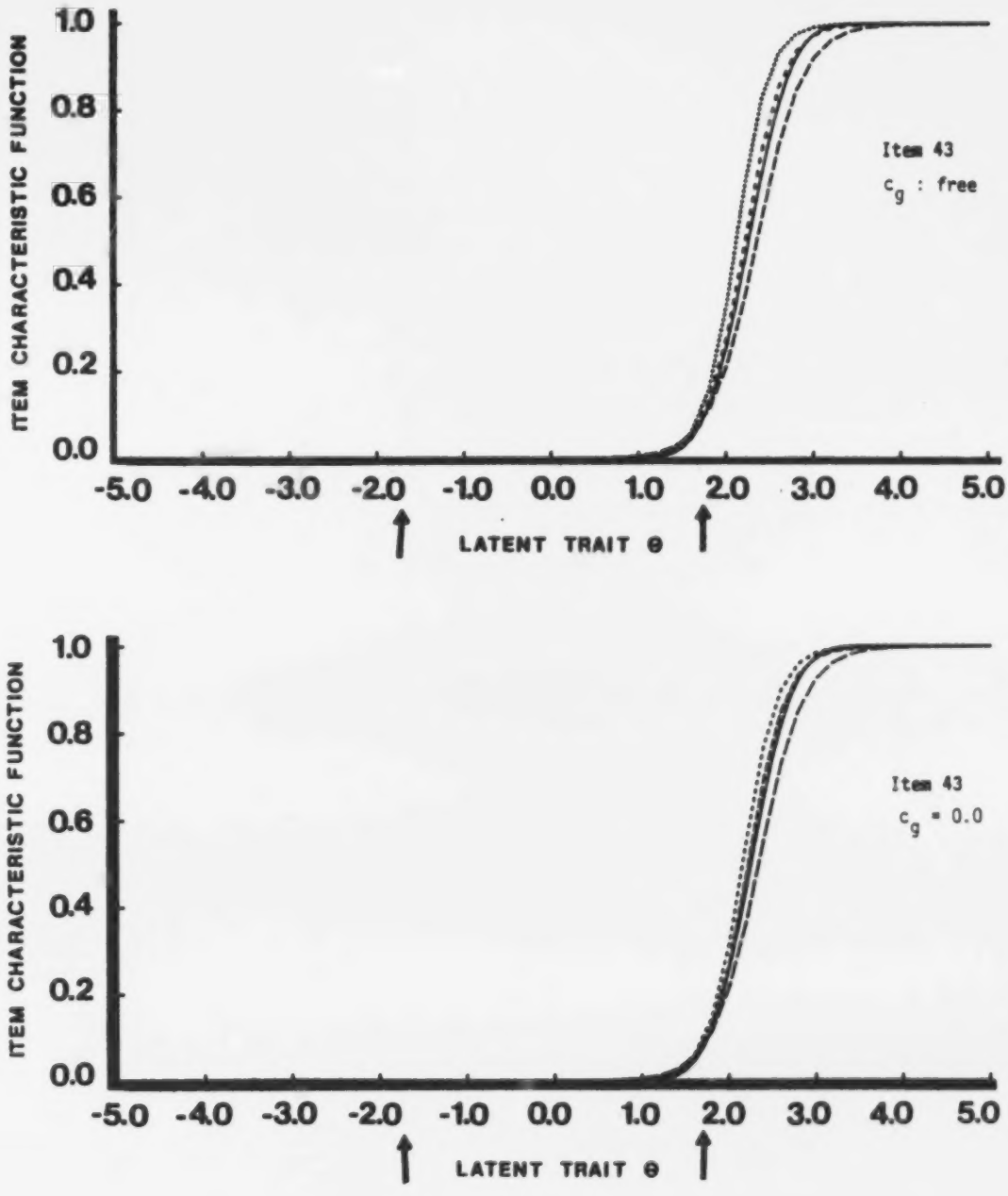

FIGURE 6-1 (Continued)

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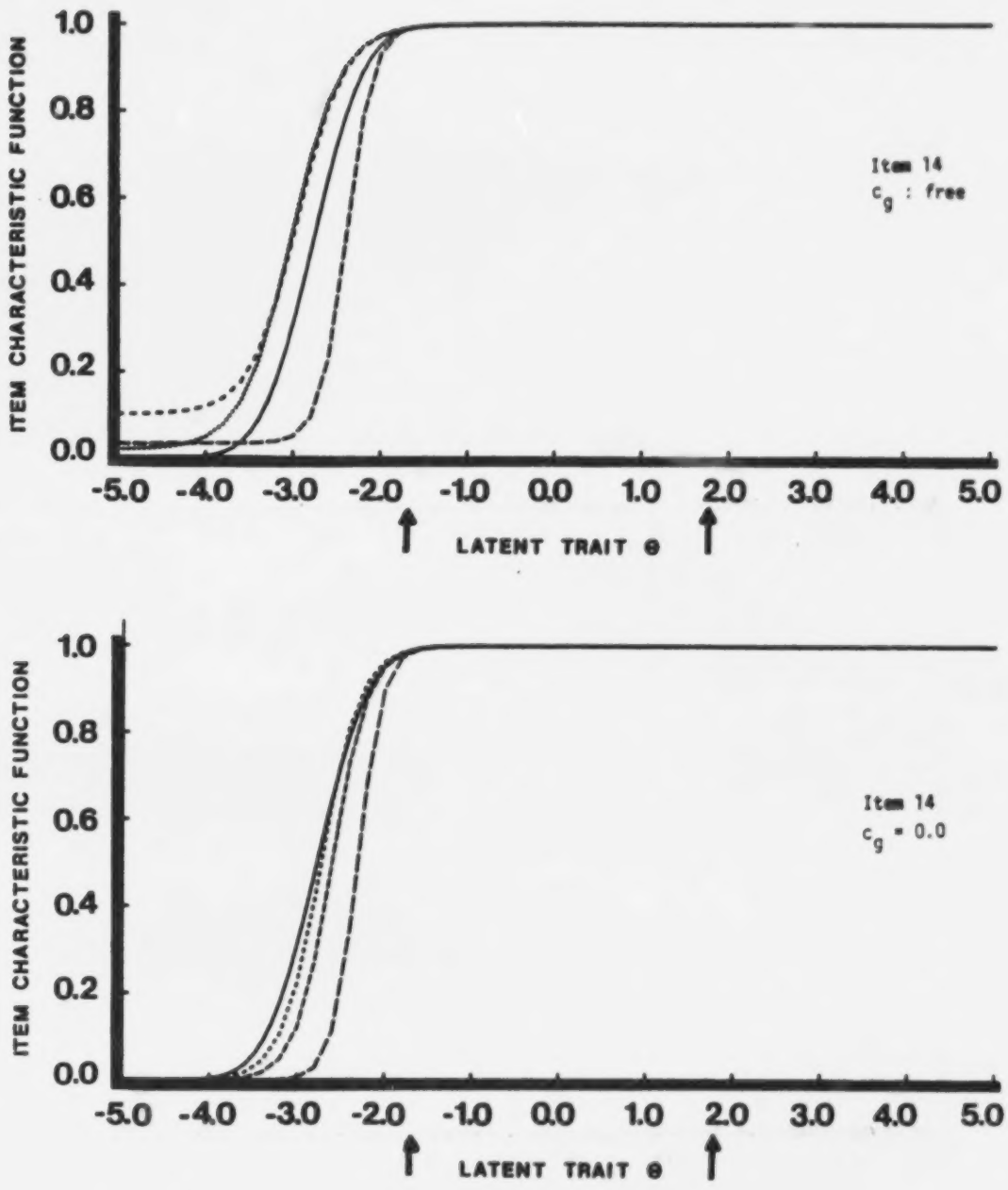

FIGURE 6-2

Theoretical Item Characteristic Function (Solid Line) of Each Item of the Thirty-Five Item Test Following the Normal Ogive Model, And Its Three Estimated Item Characteristic Functions Following the Three-Parameter Logistic Model Using LOGIST 5 , Which Are Based upon the Thirty-Five Item Test (Dotted Line), the Forty-Five Item Test (Short Dashed Line) and the Eighty Item Test (Long Dashed Line), Respectively. The Guessing Parameter Is Set Free in the Upper Graph, And Set Equal to Zero in the Lower Graph.

2,000 Subject Case.

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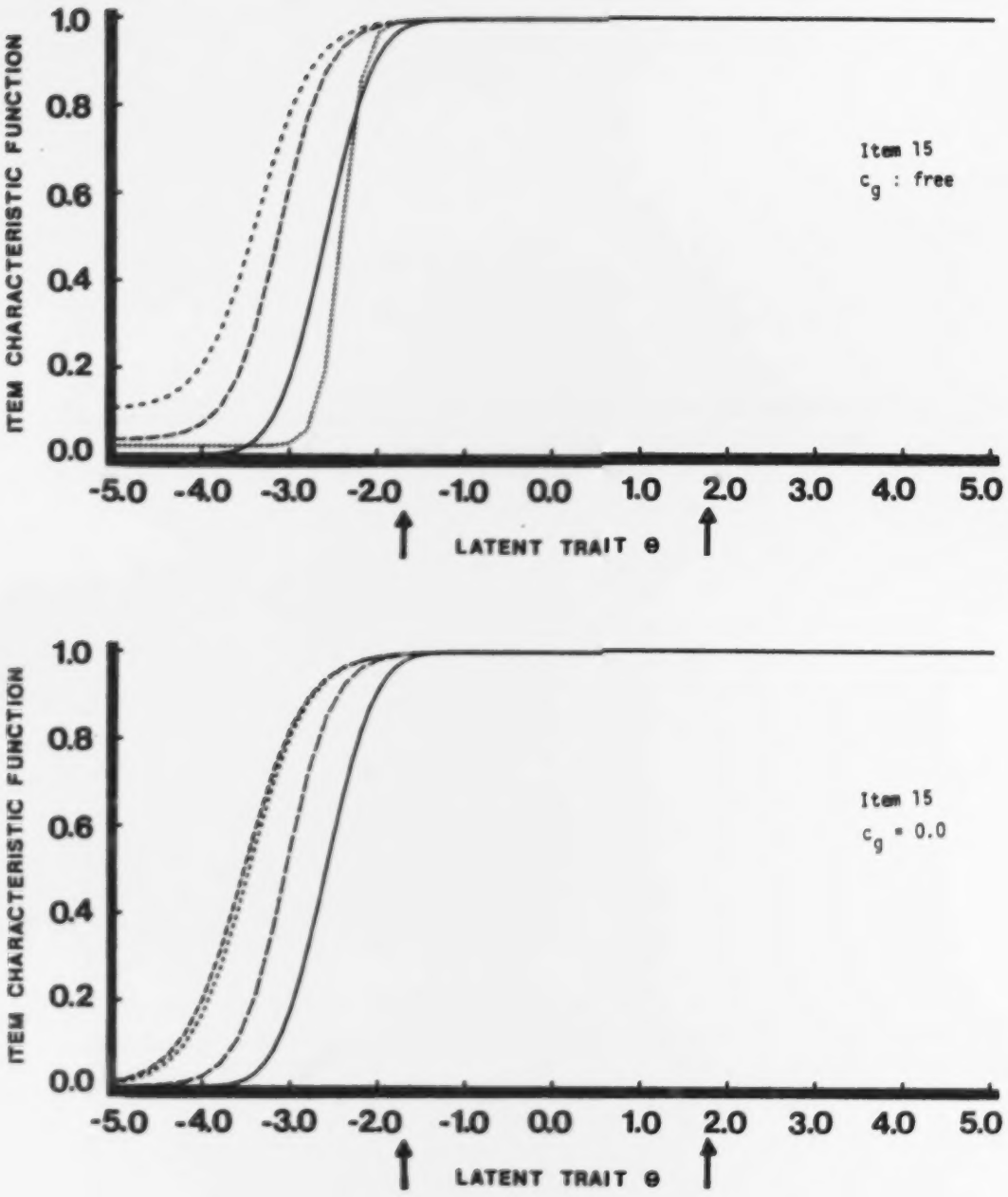


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

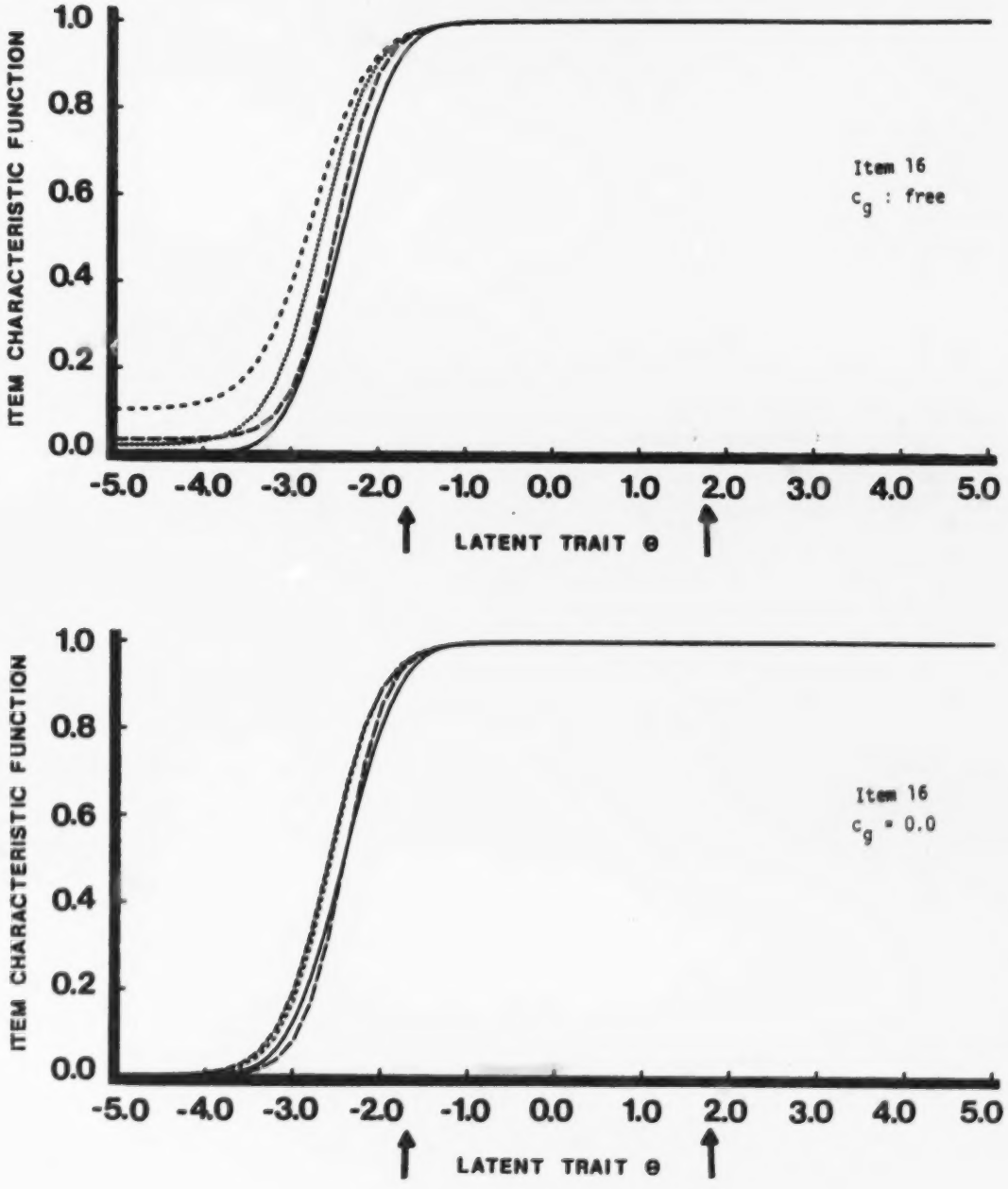


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

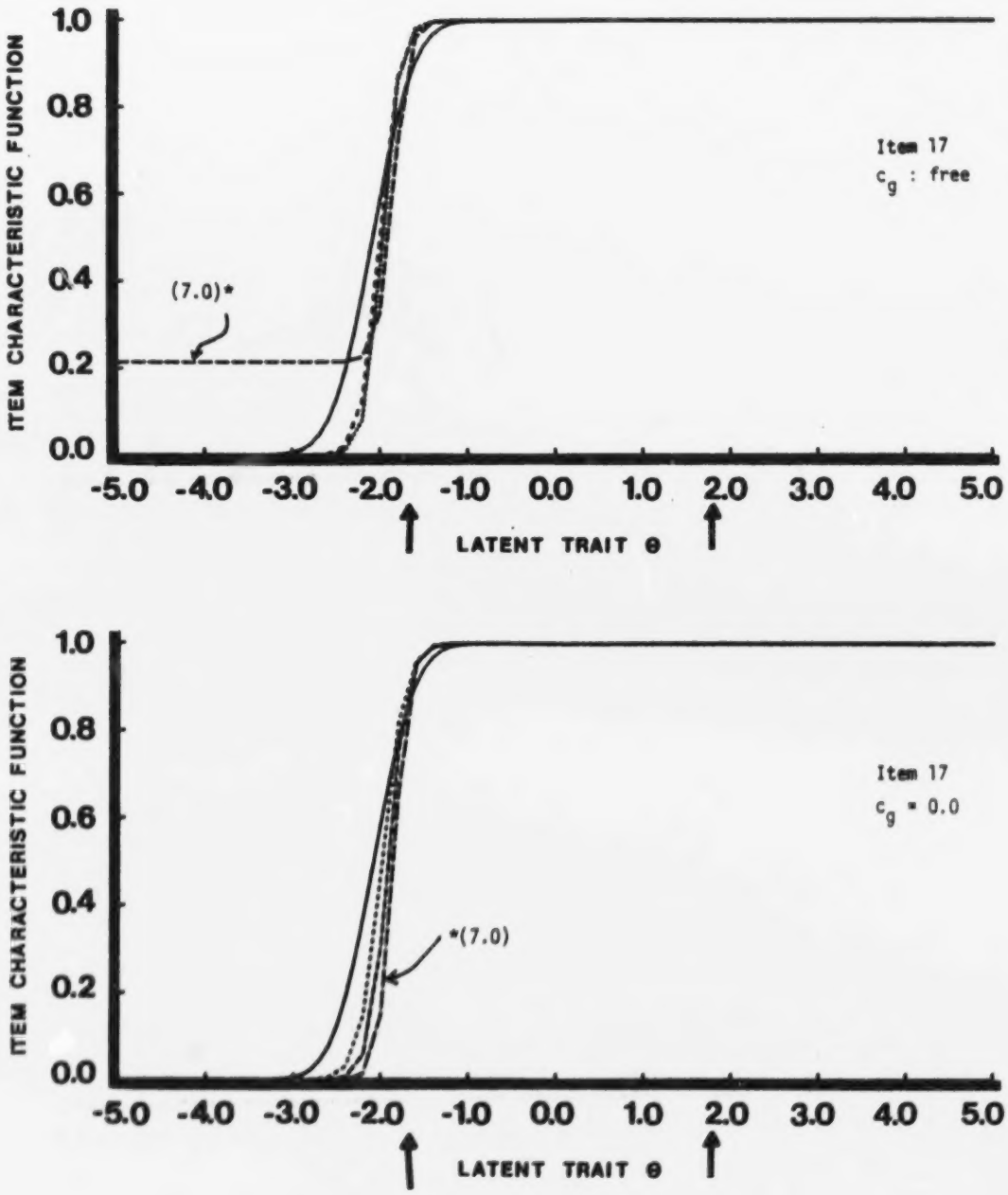


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

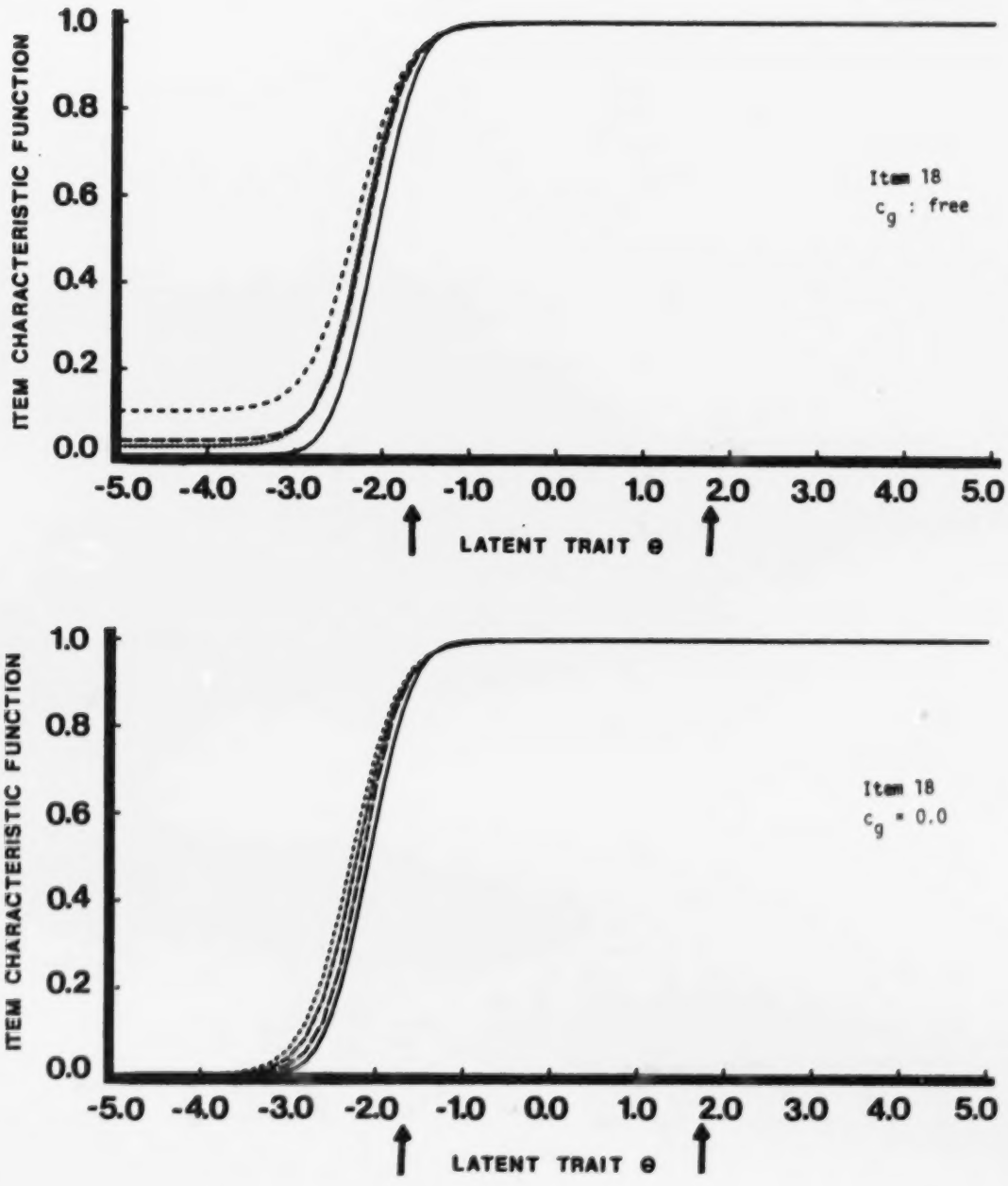


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

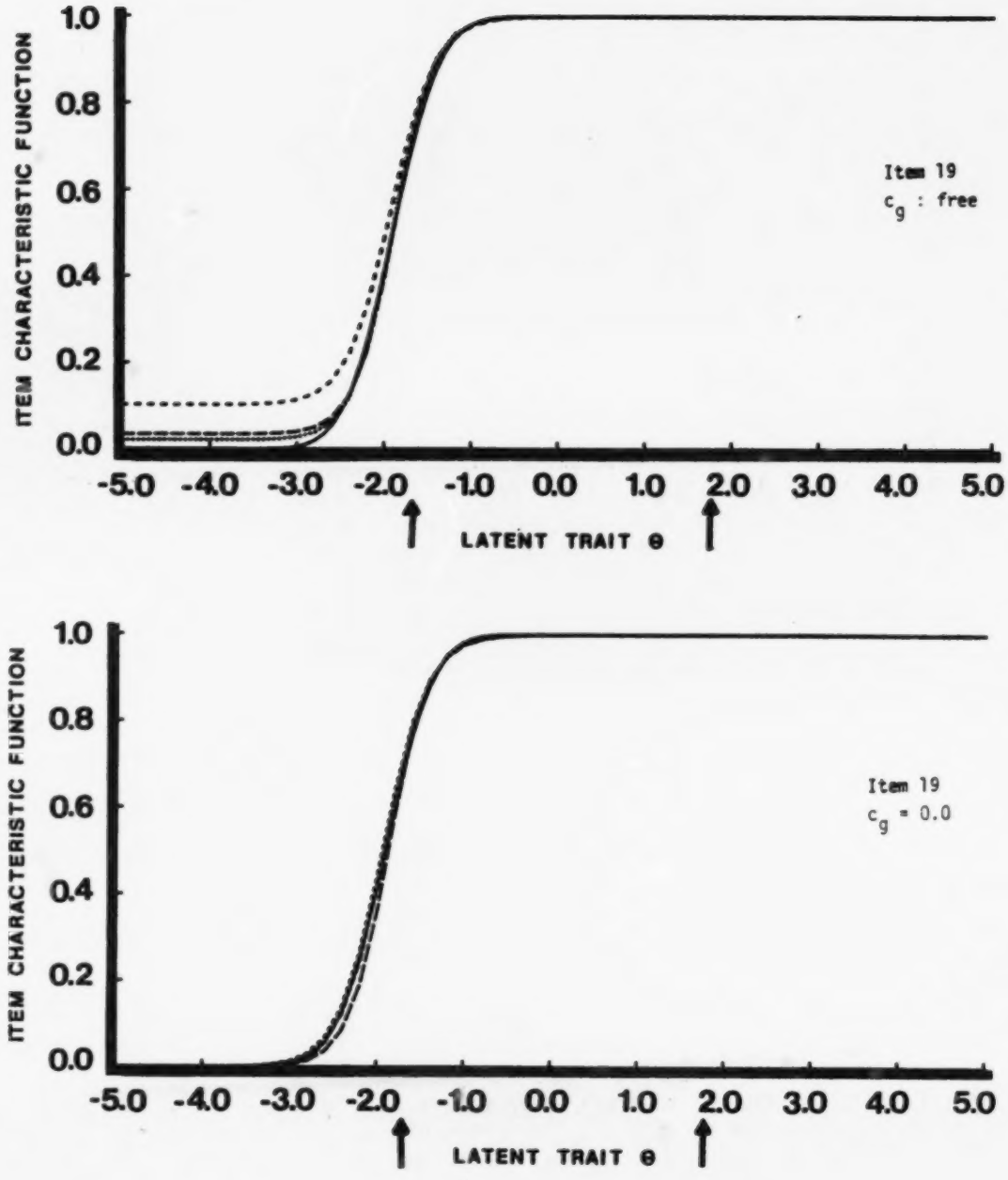


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

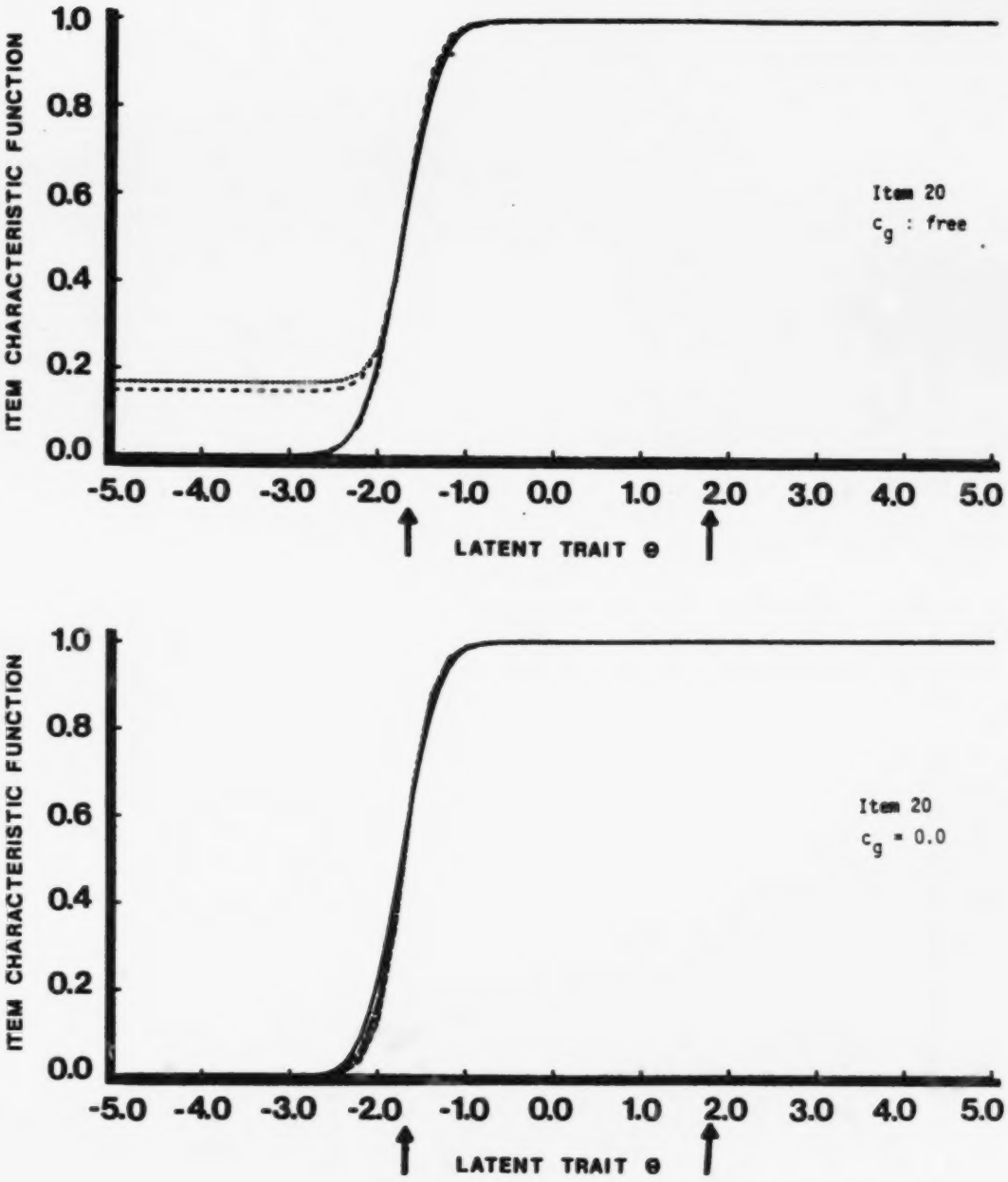


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

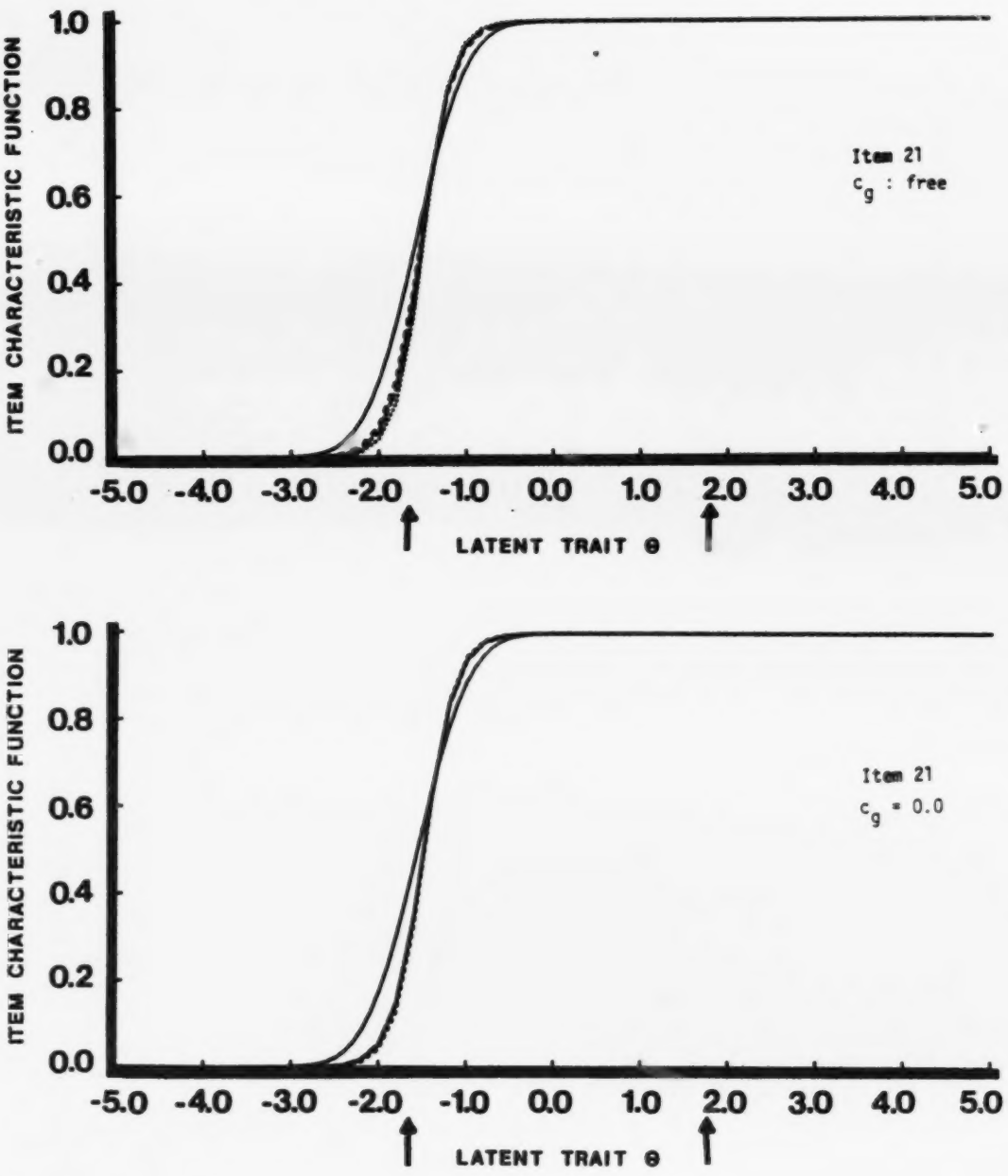


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

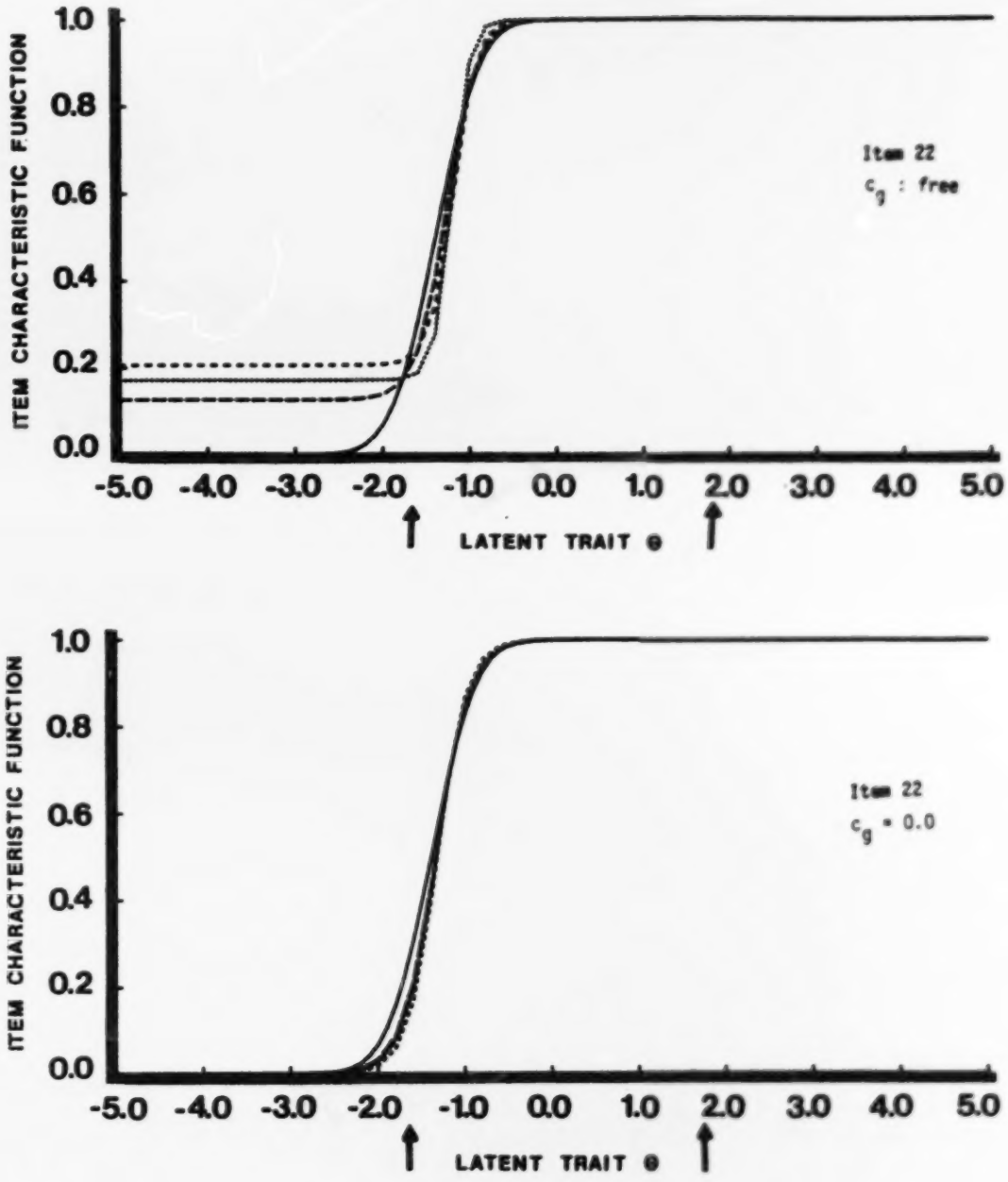


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

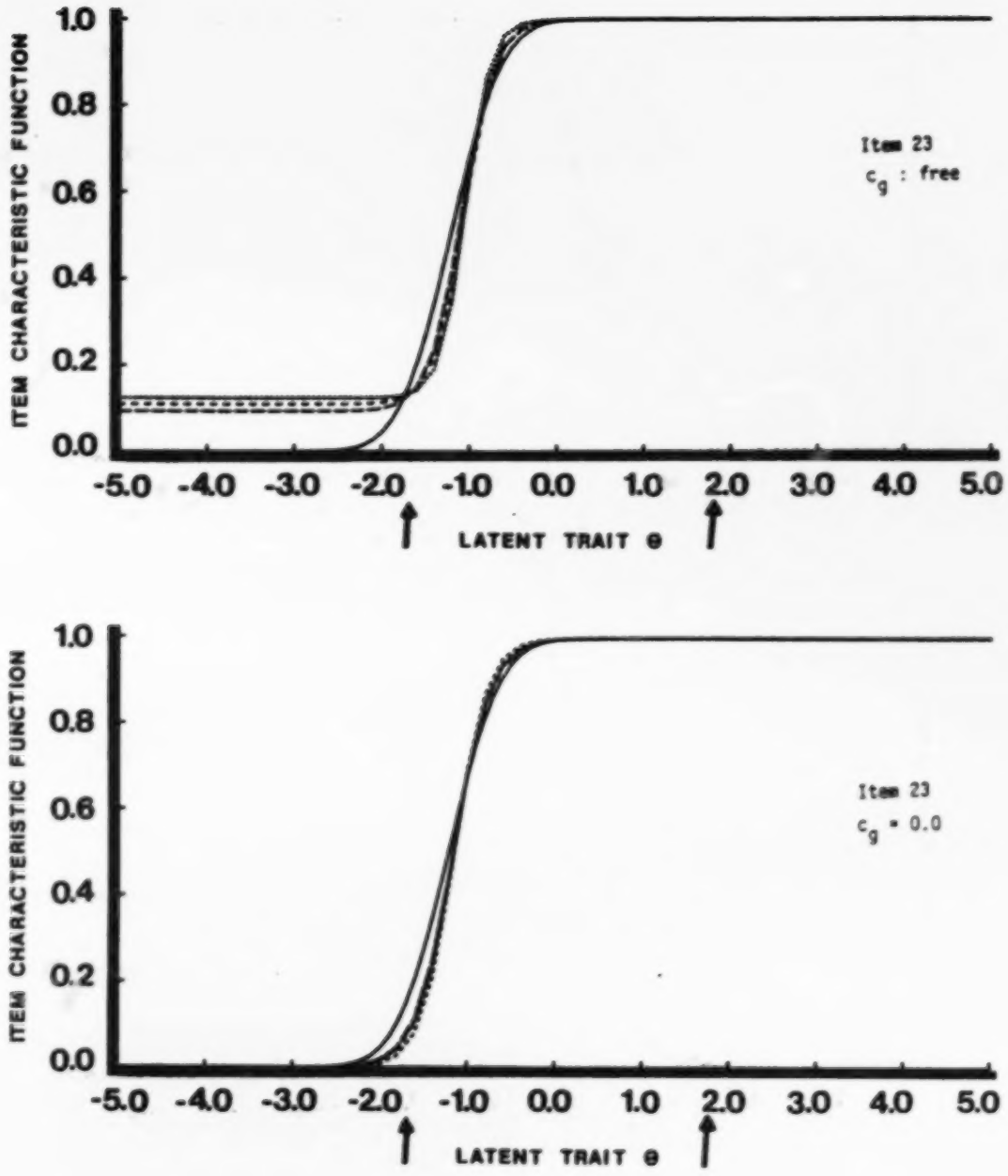


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

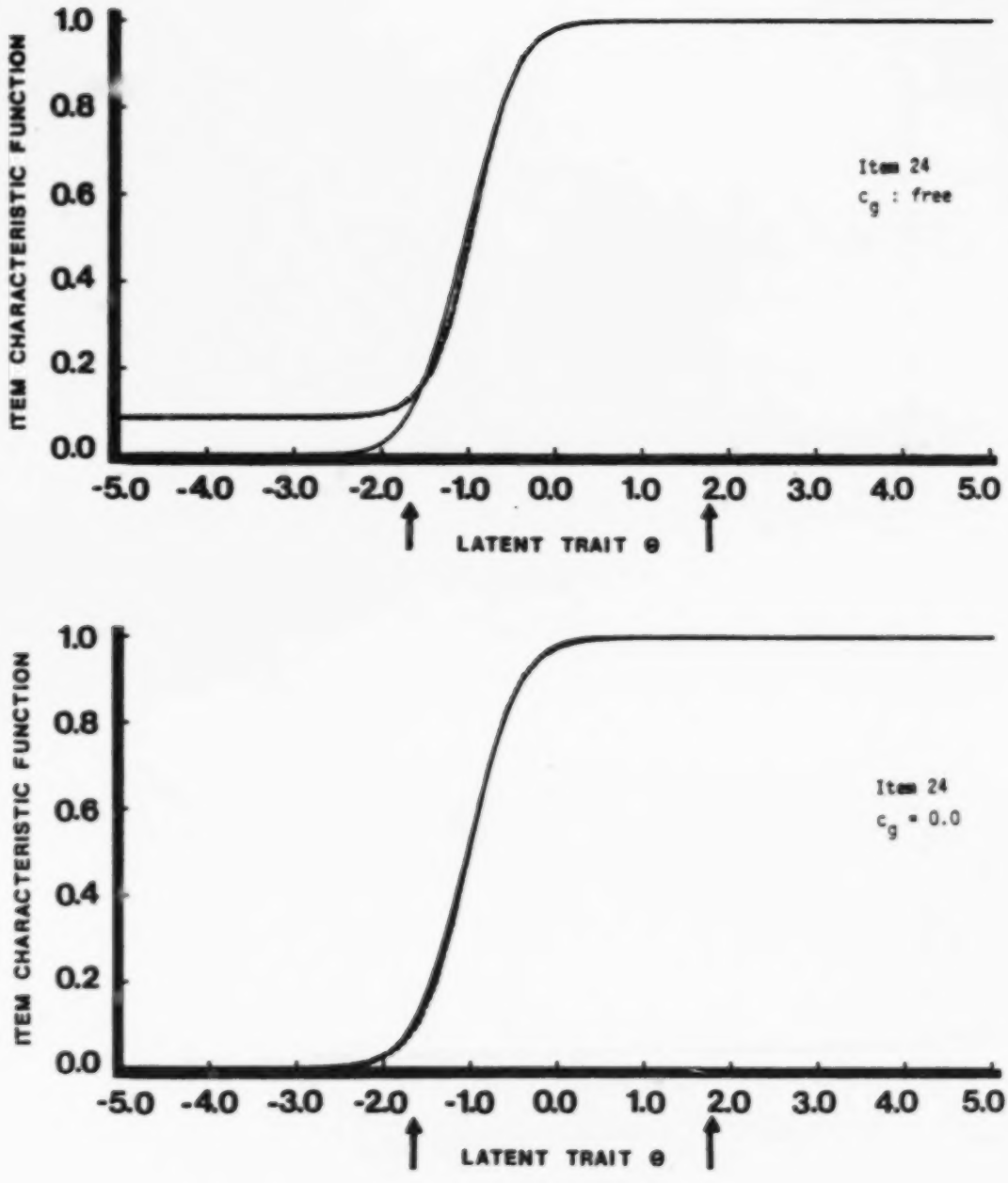


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

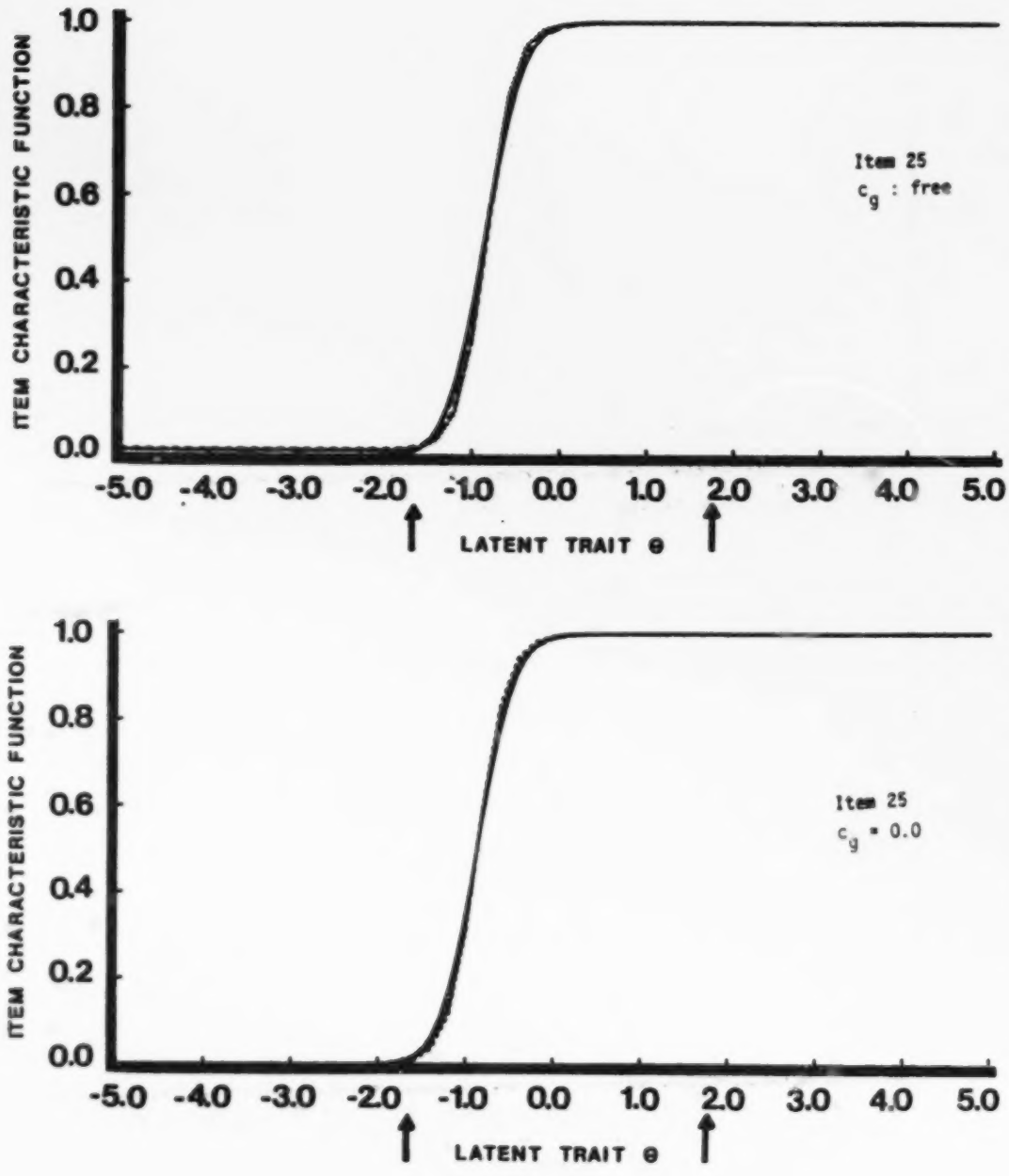


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

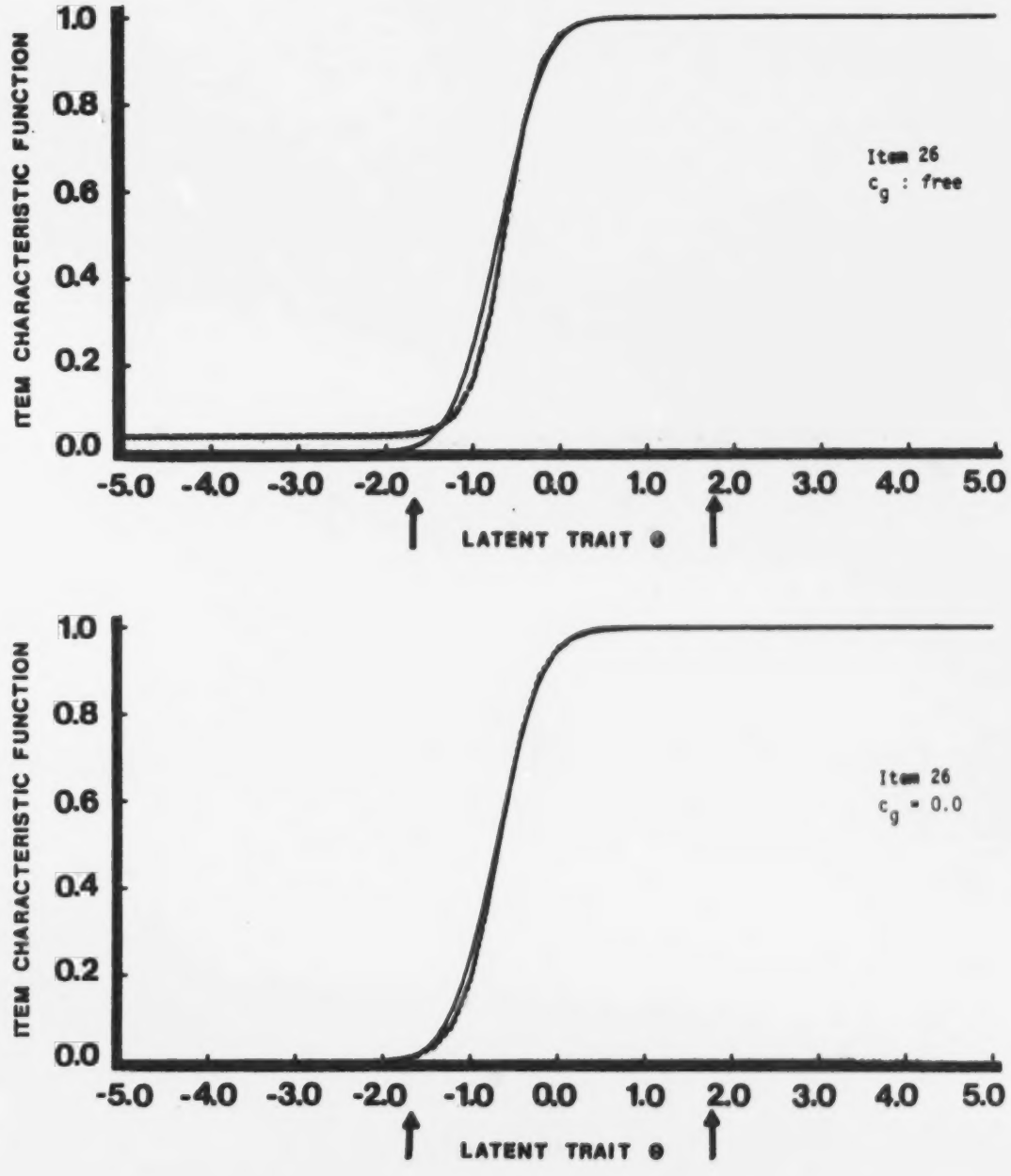
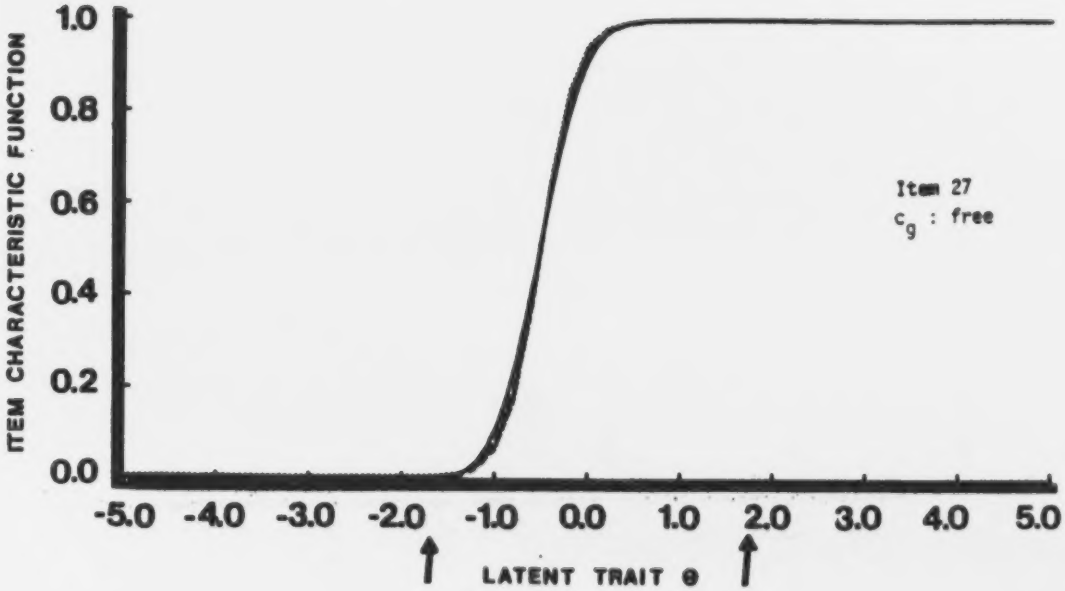


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case



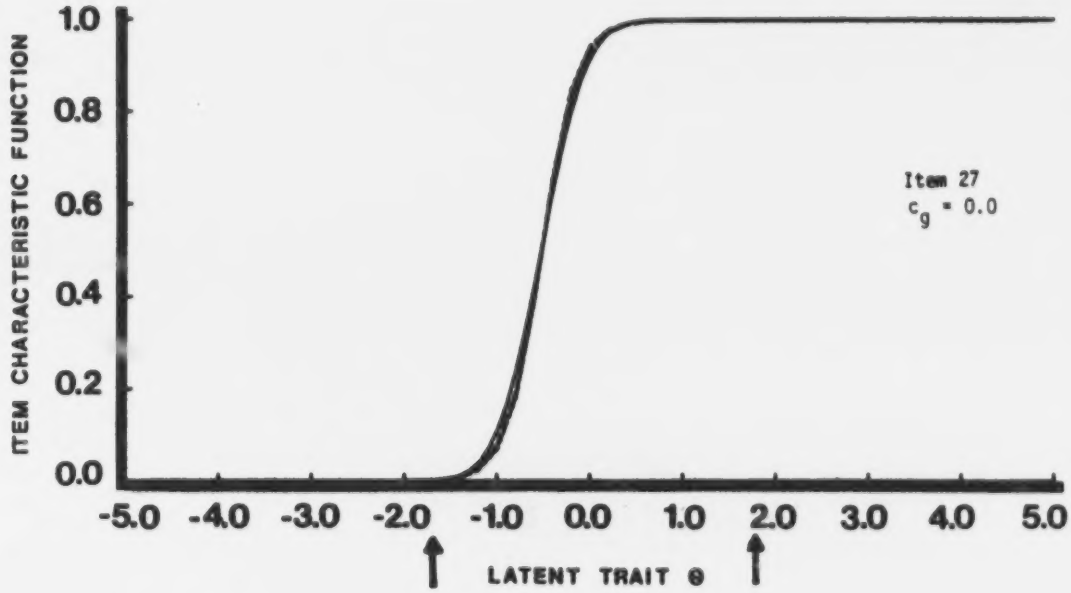


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

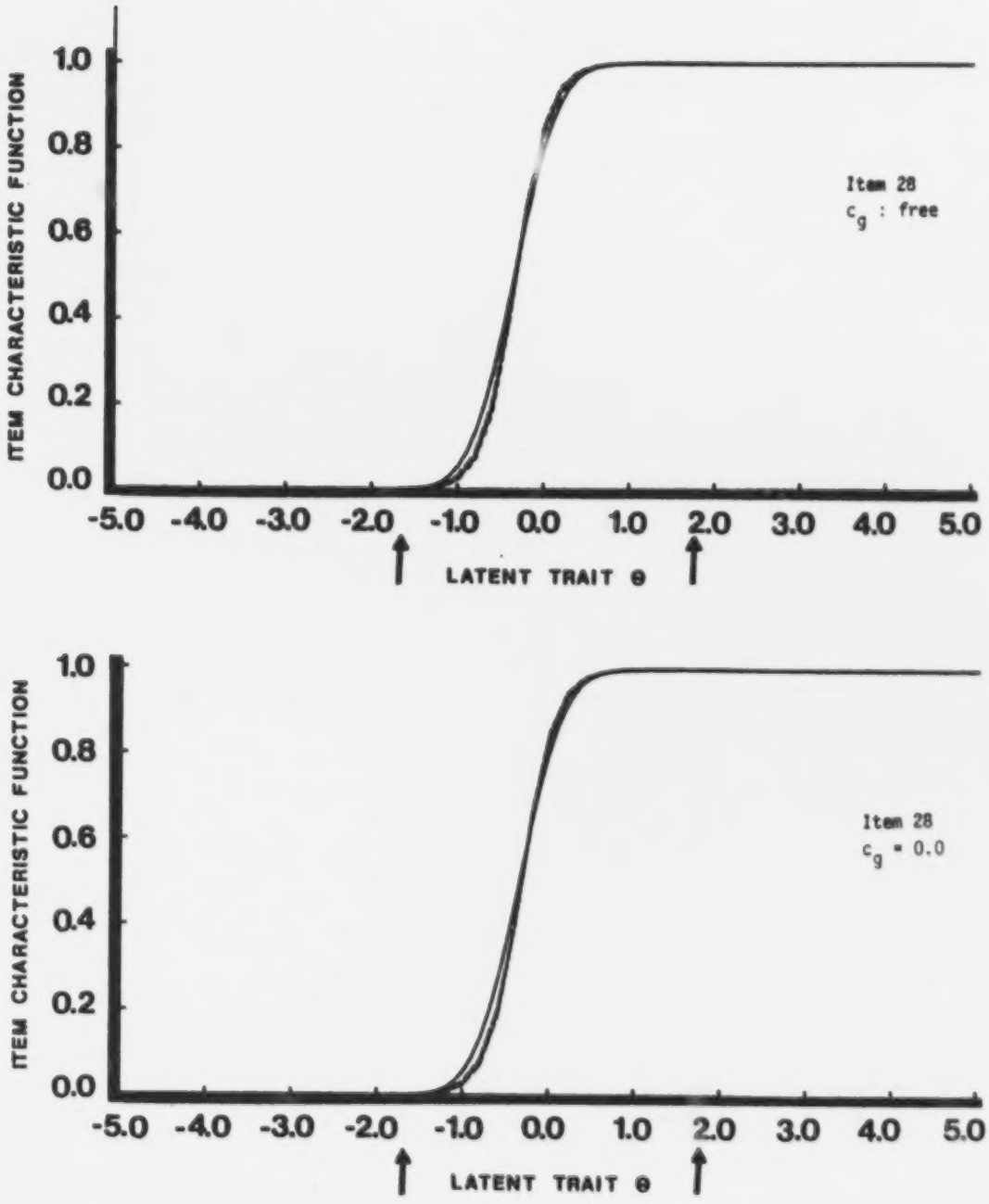


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

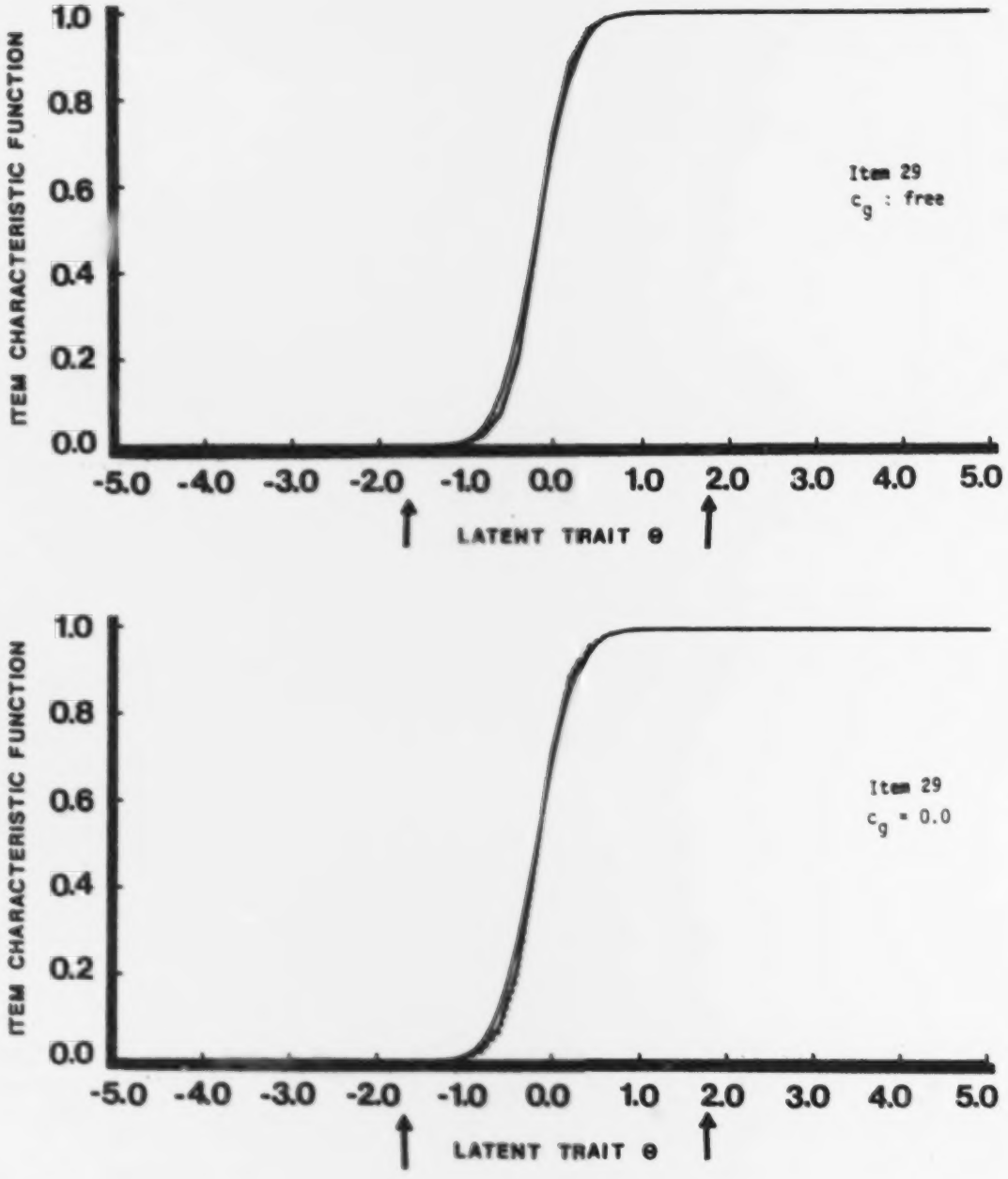


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

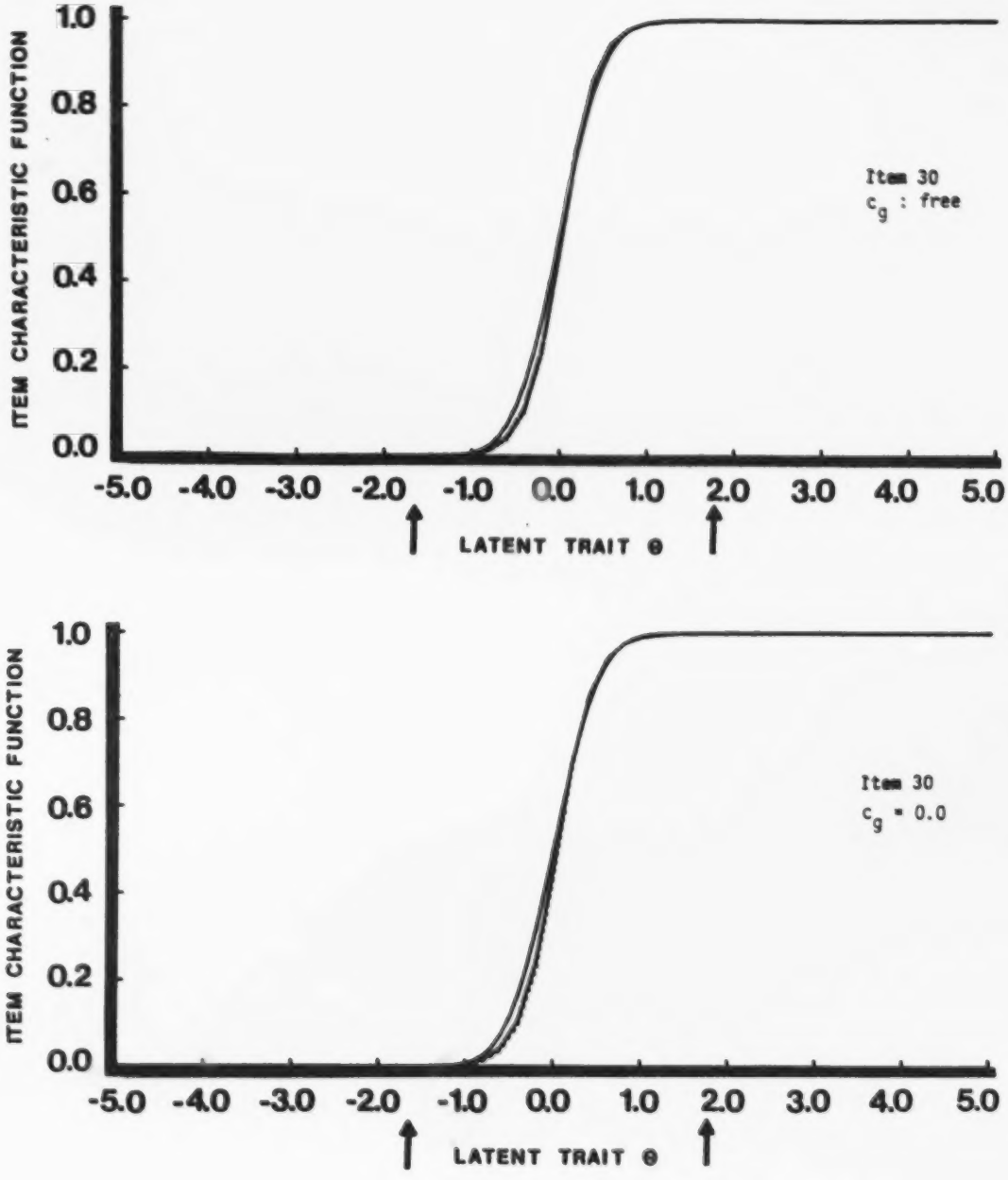


FIGURE 6-2 (Continued)

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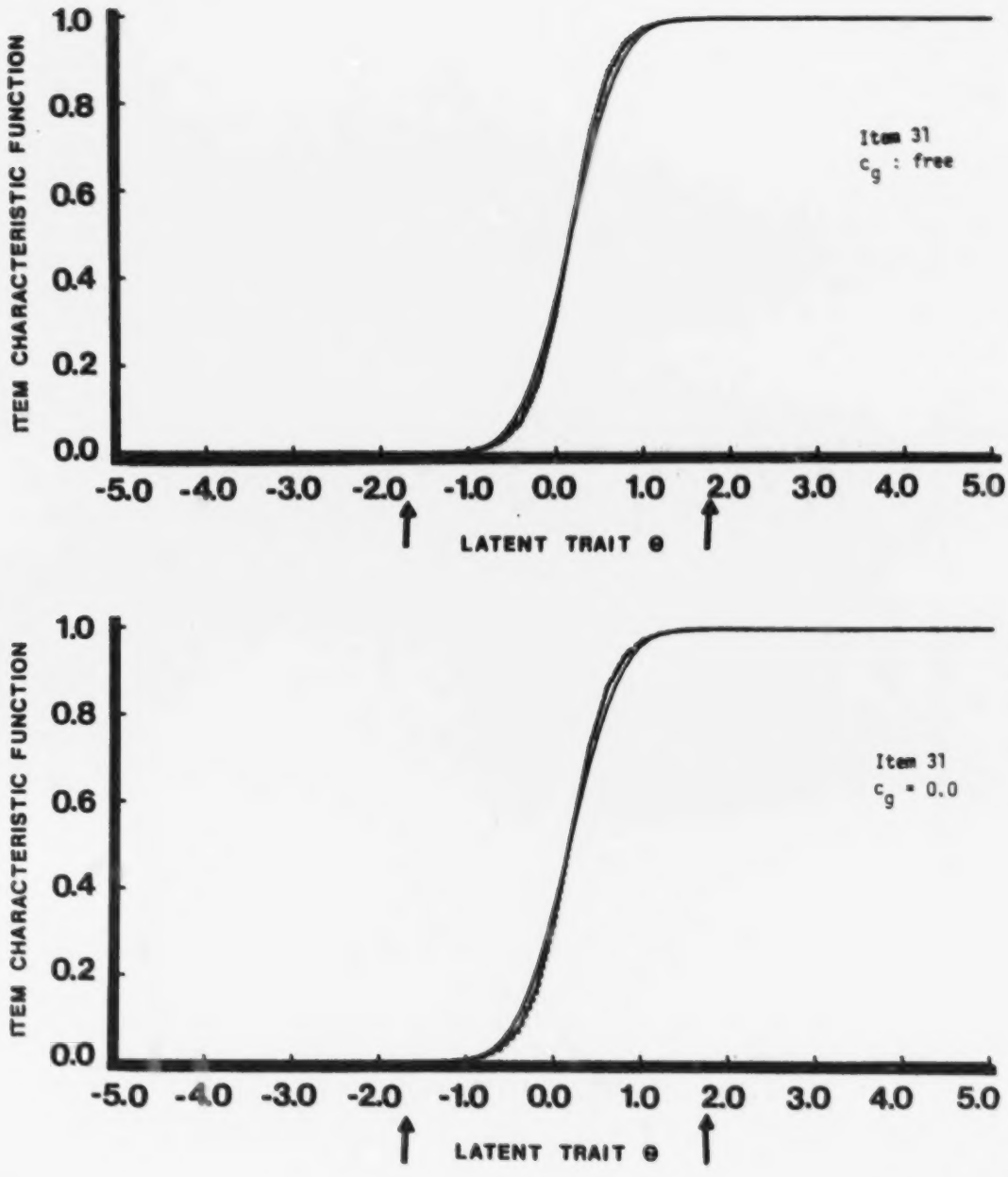

FIGURE 6-2 (Continued)

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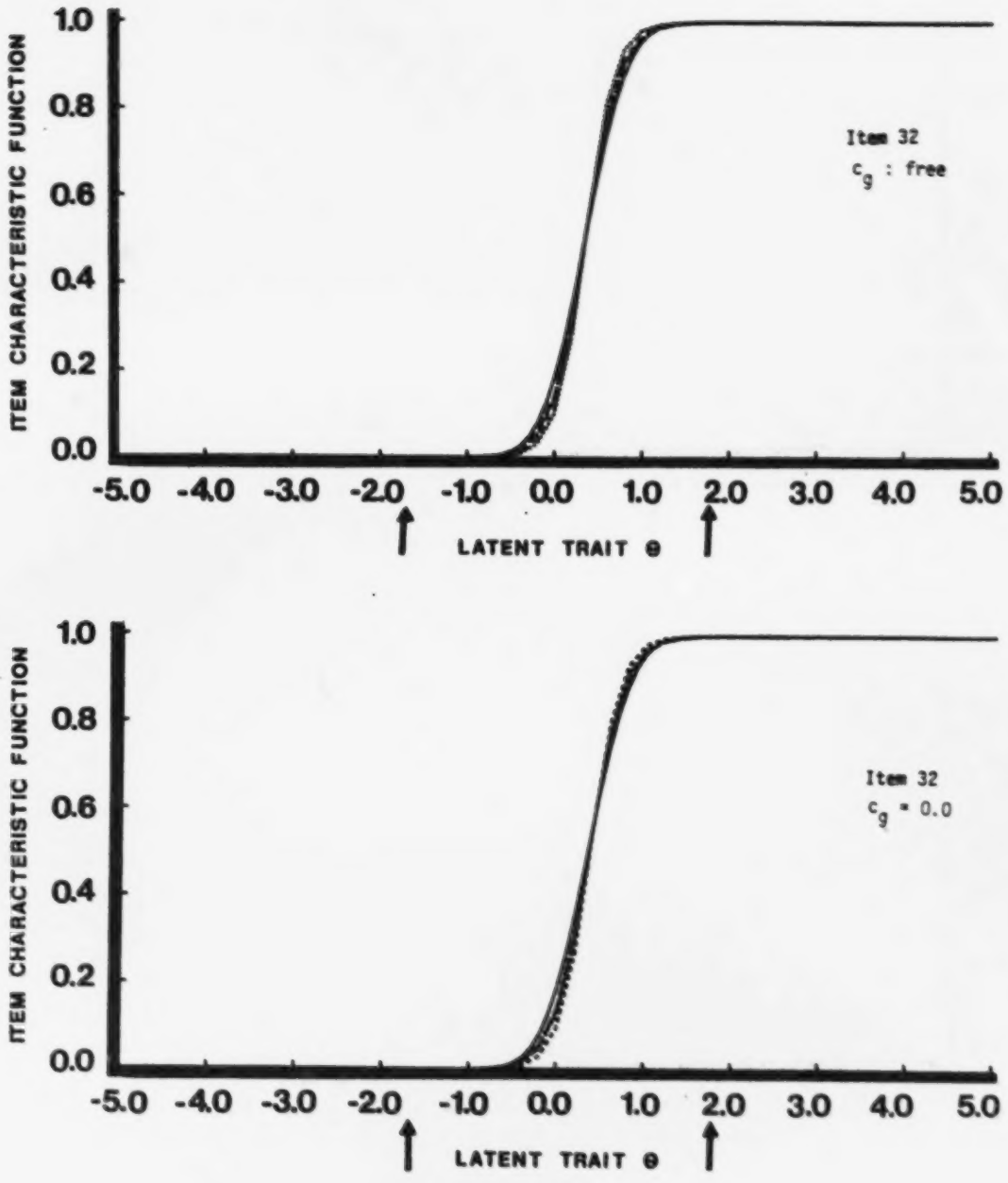

FIGURE 6-2 (Continued)

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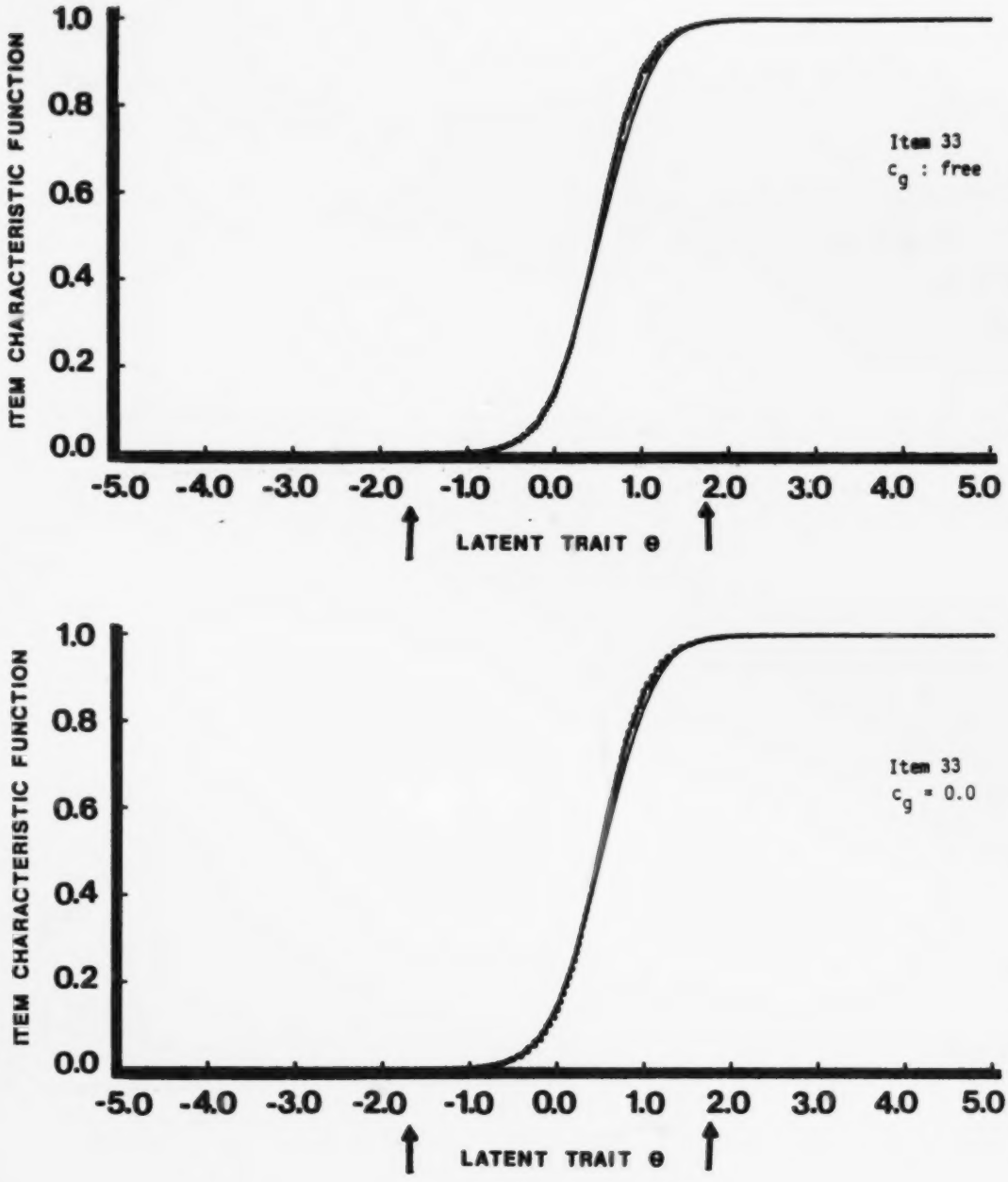
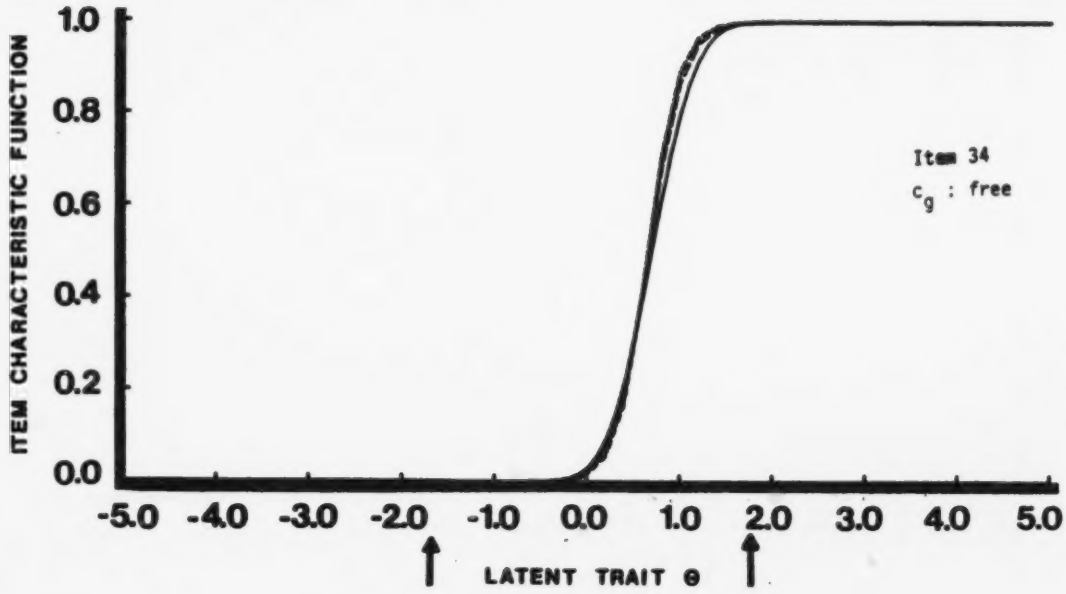


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case



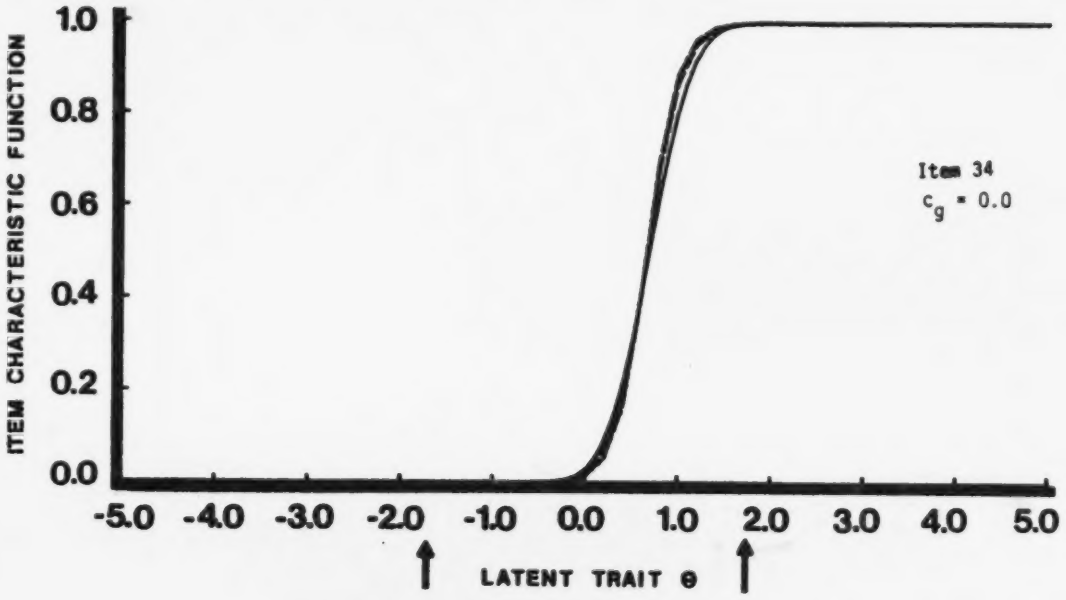


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

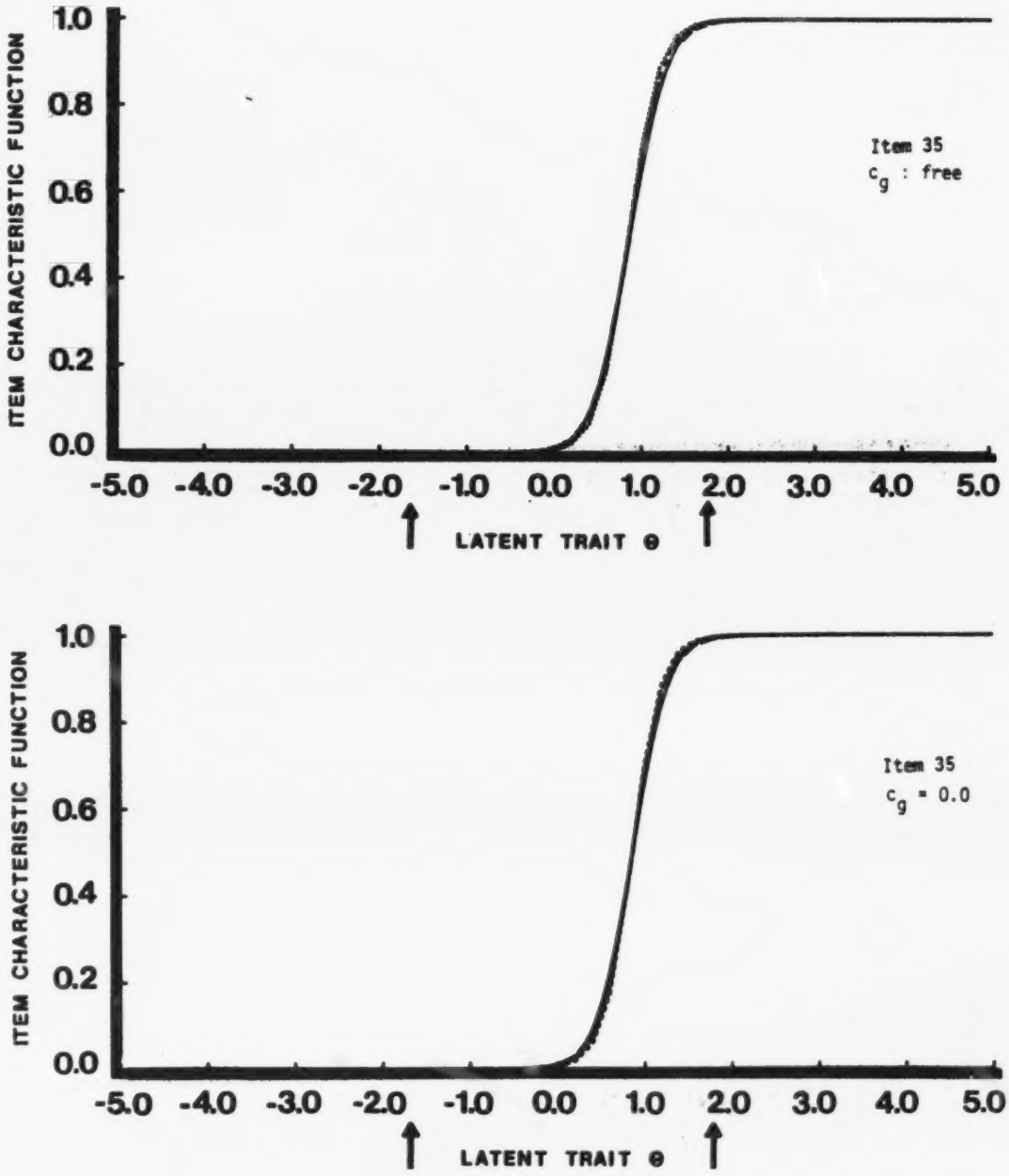


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

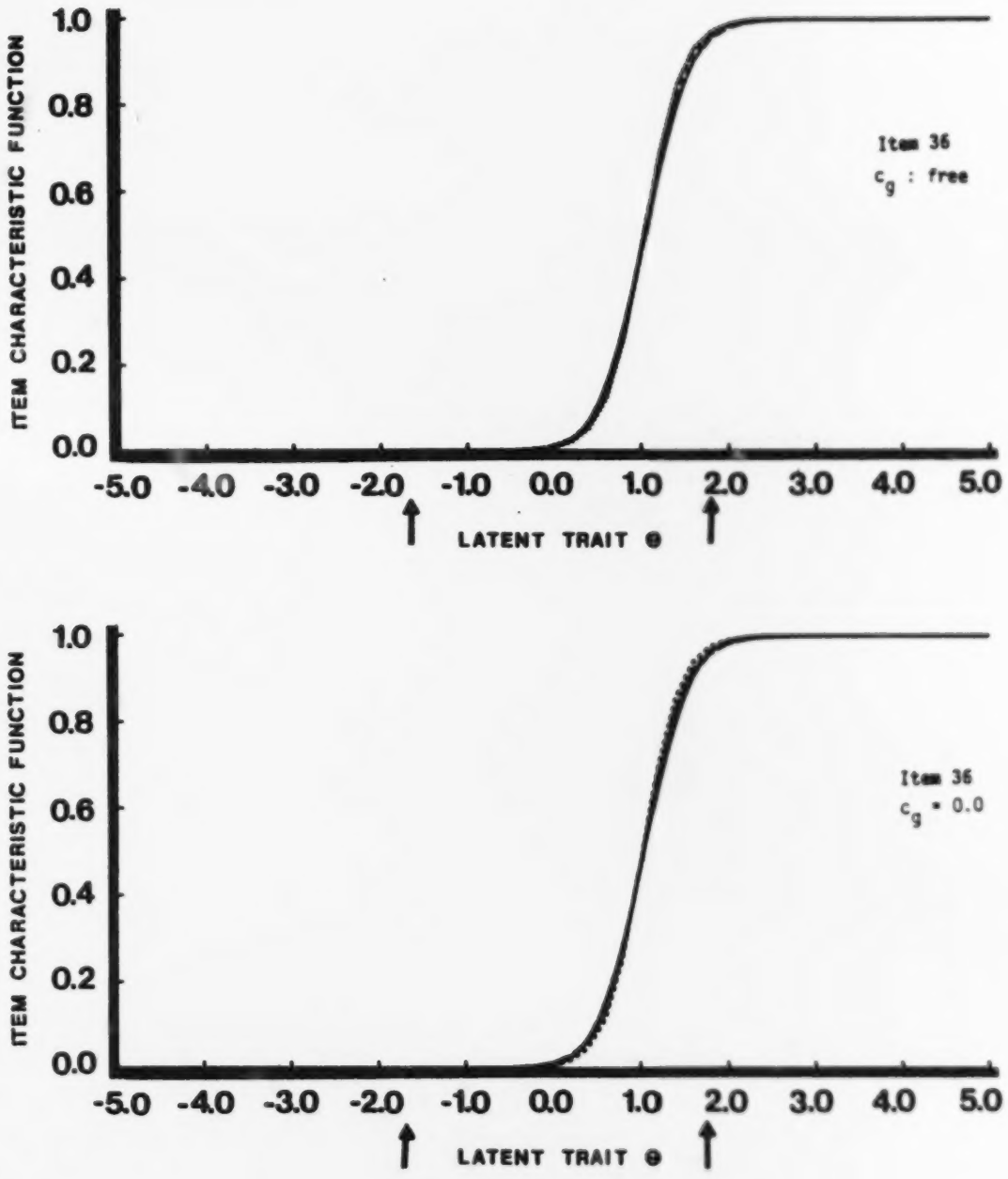
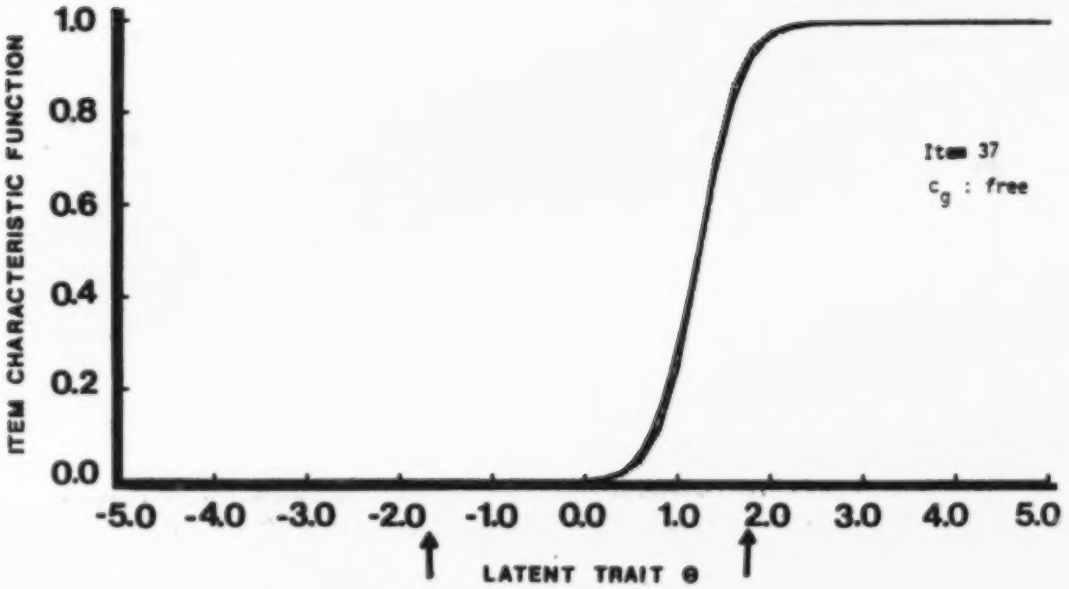


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case



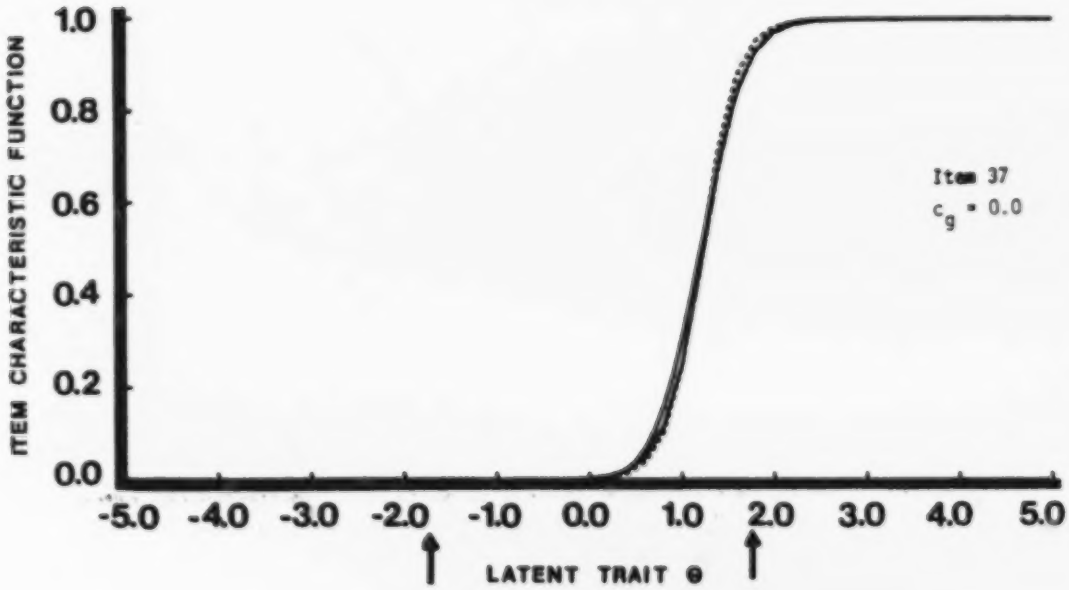


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

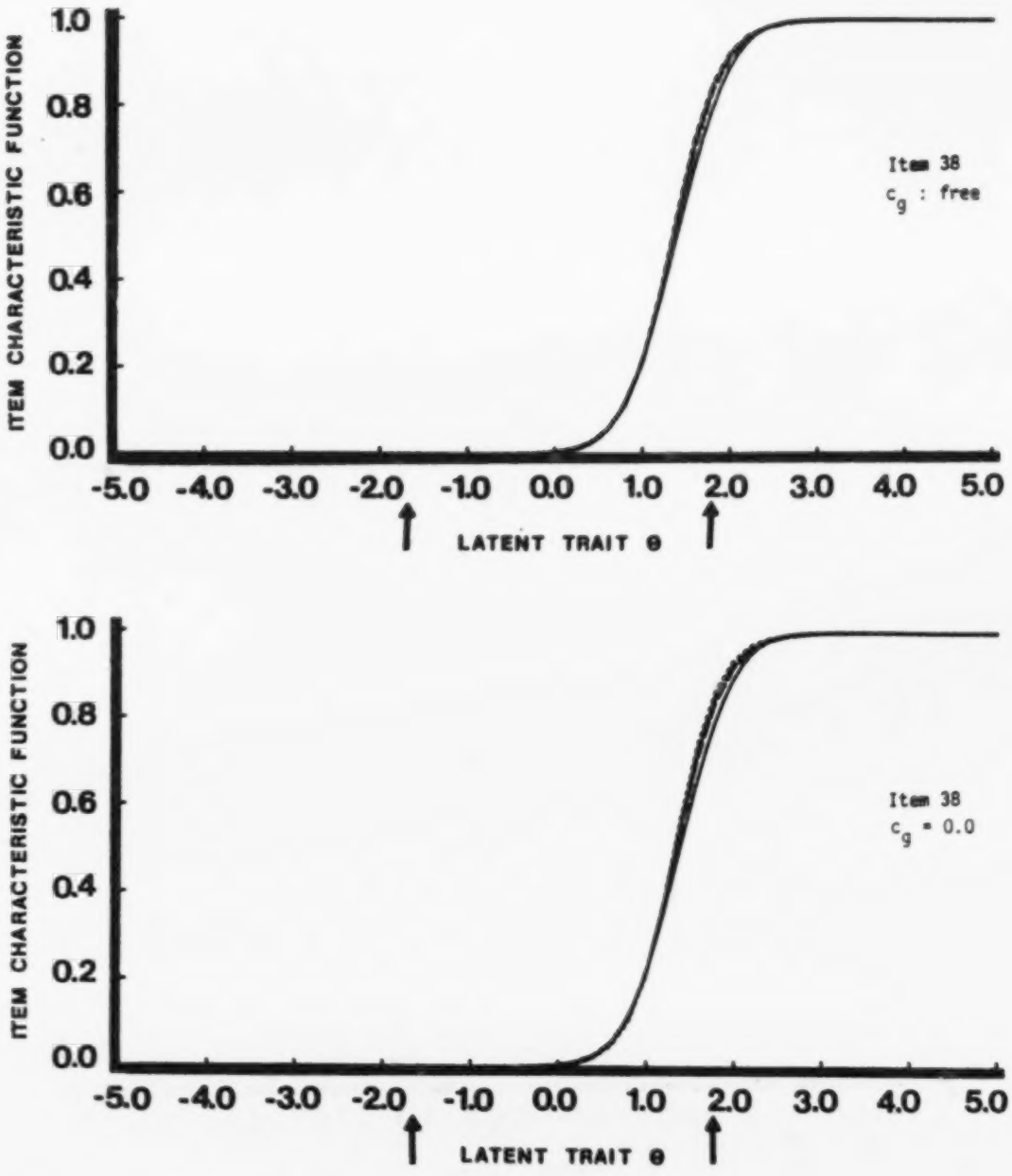


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

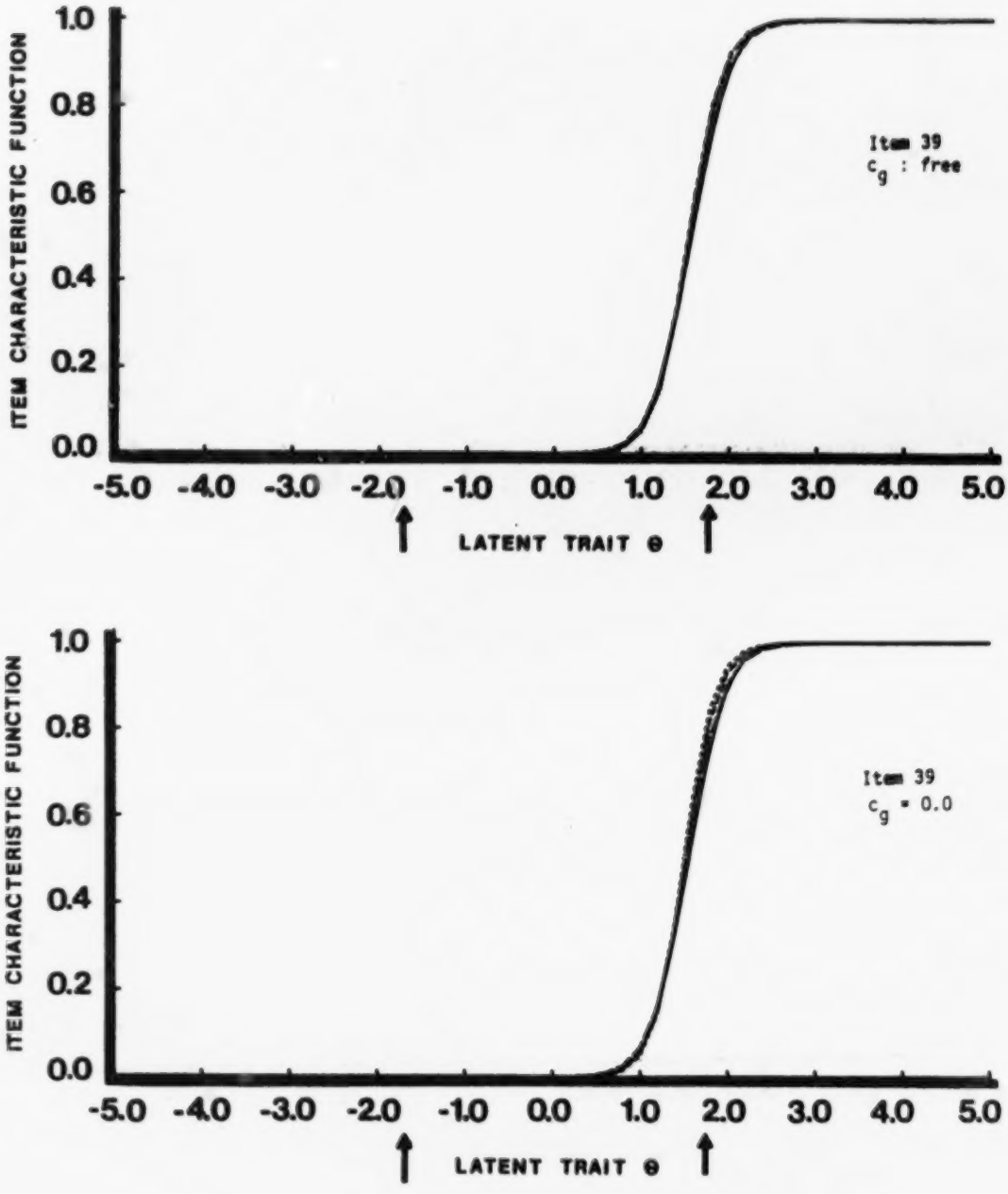
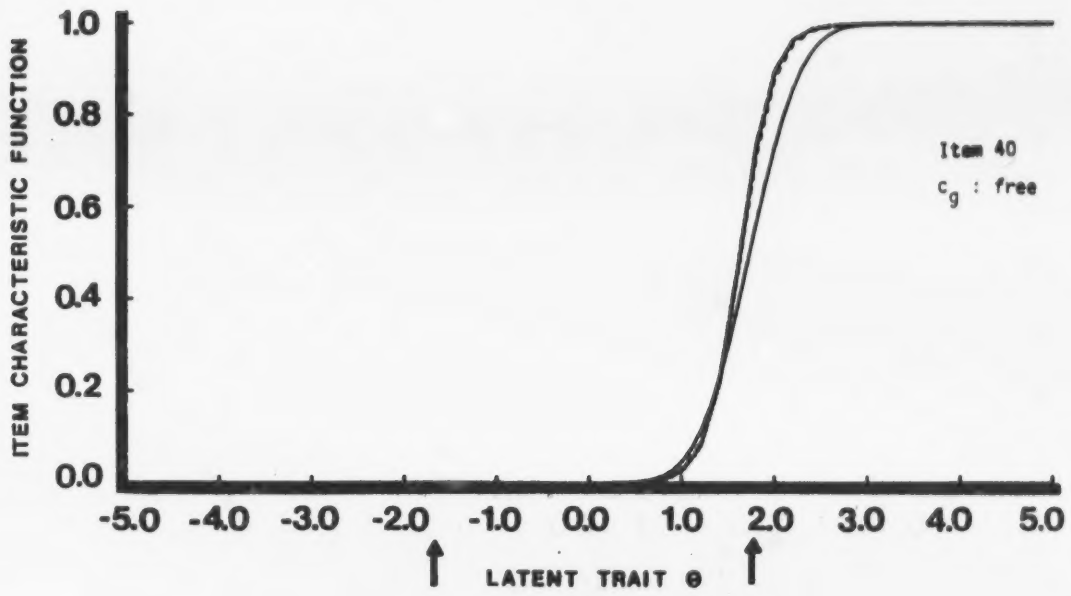


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case



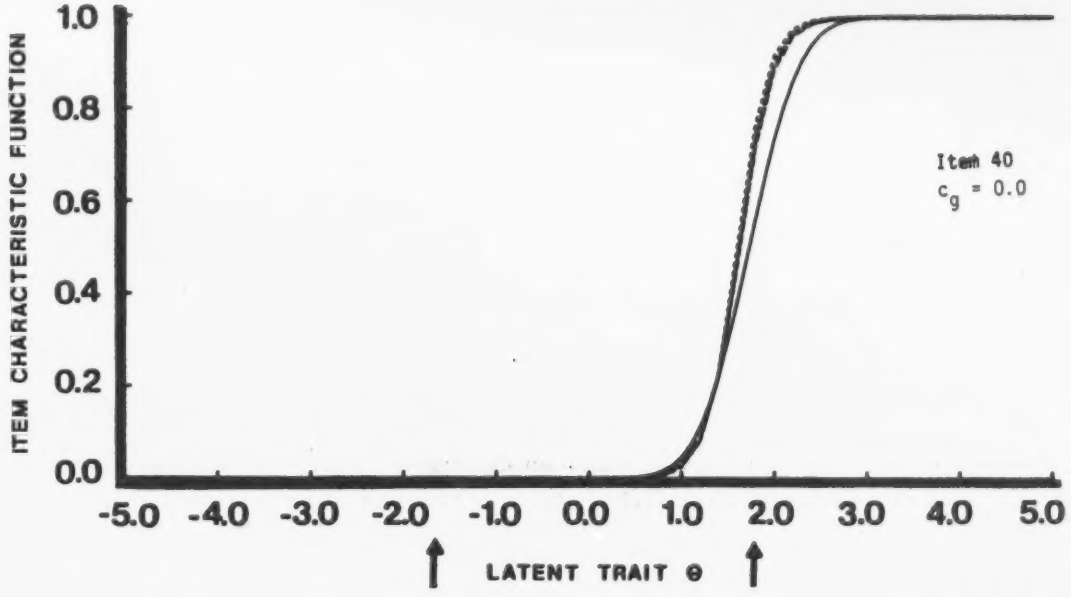
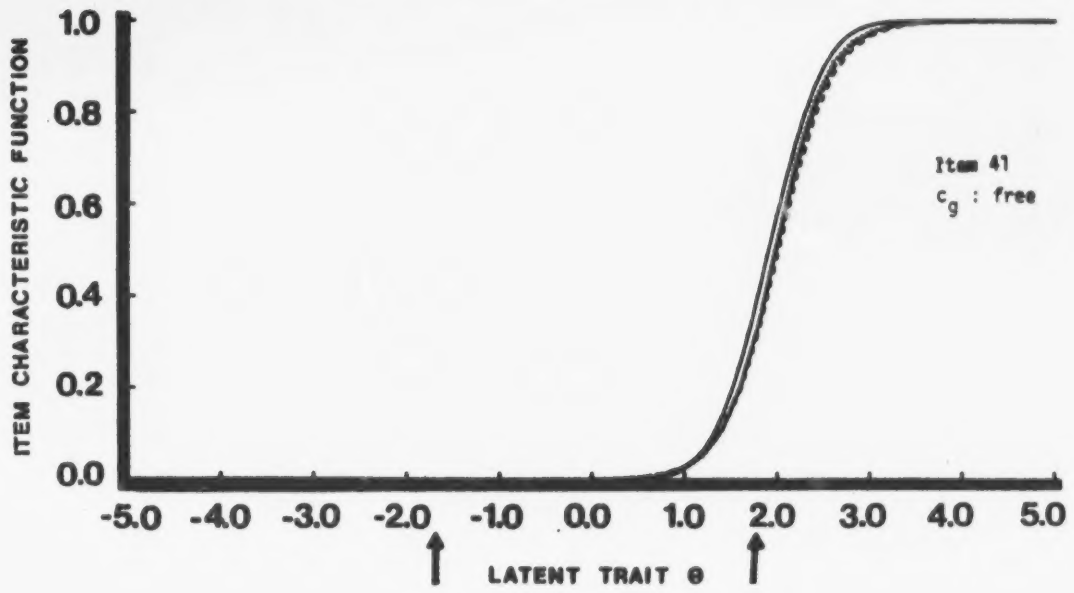


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case



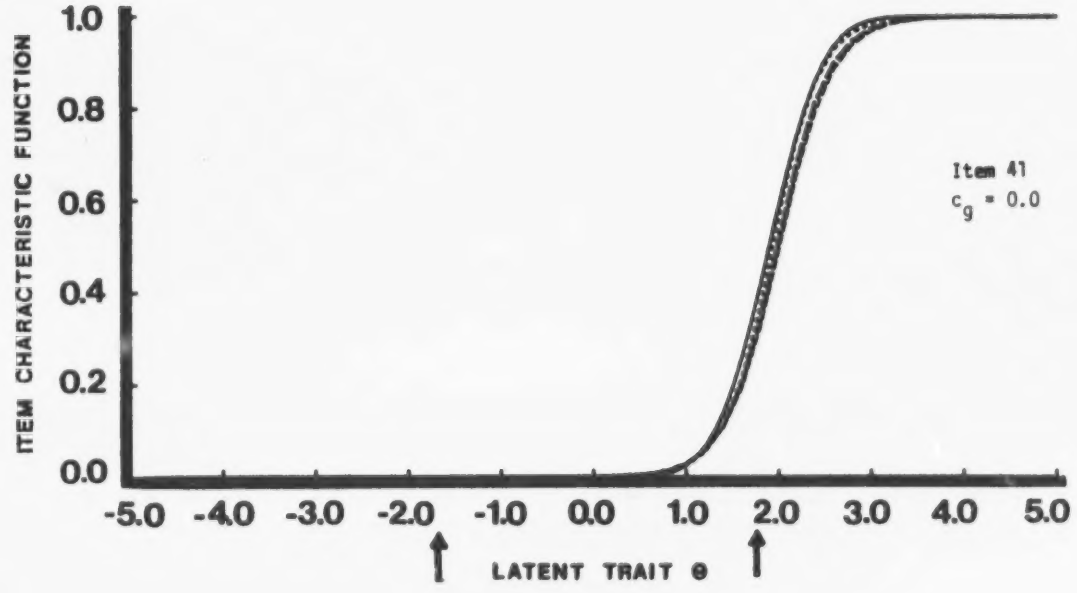


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

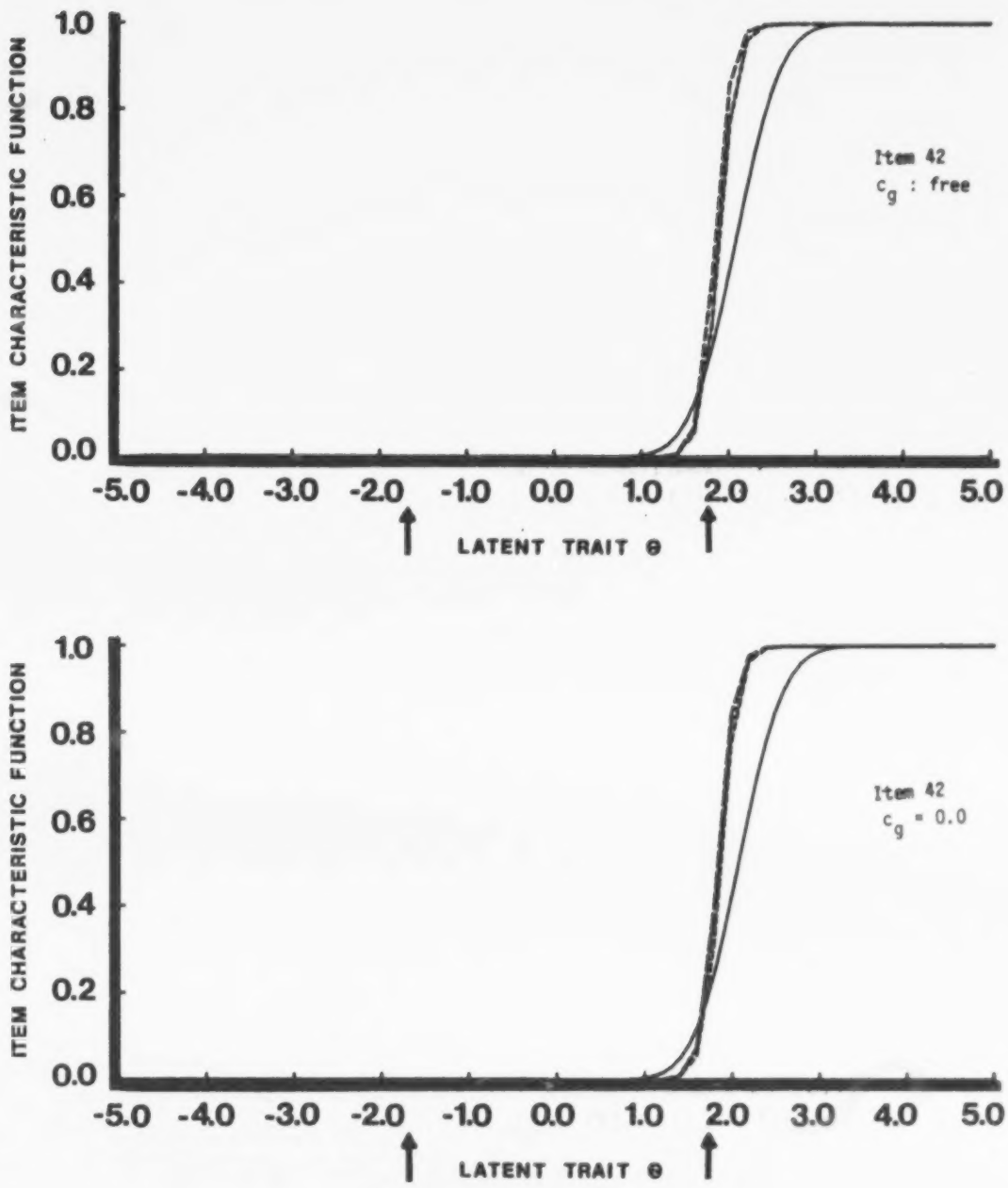
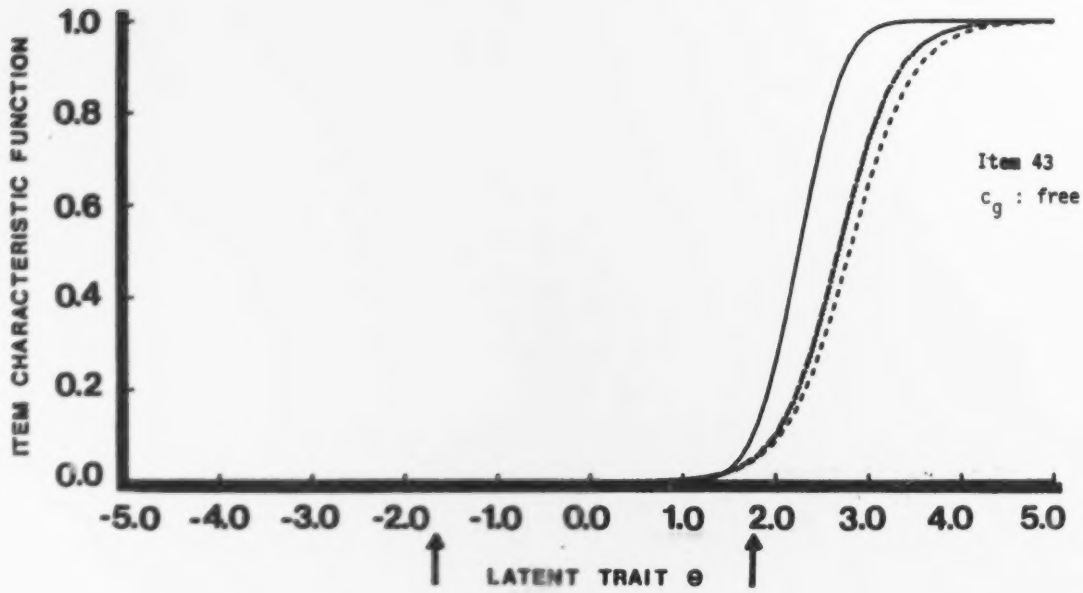


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case



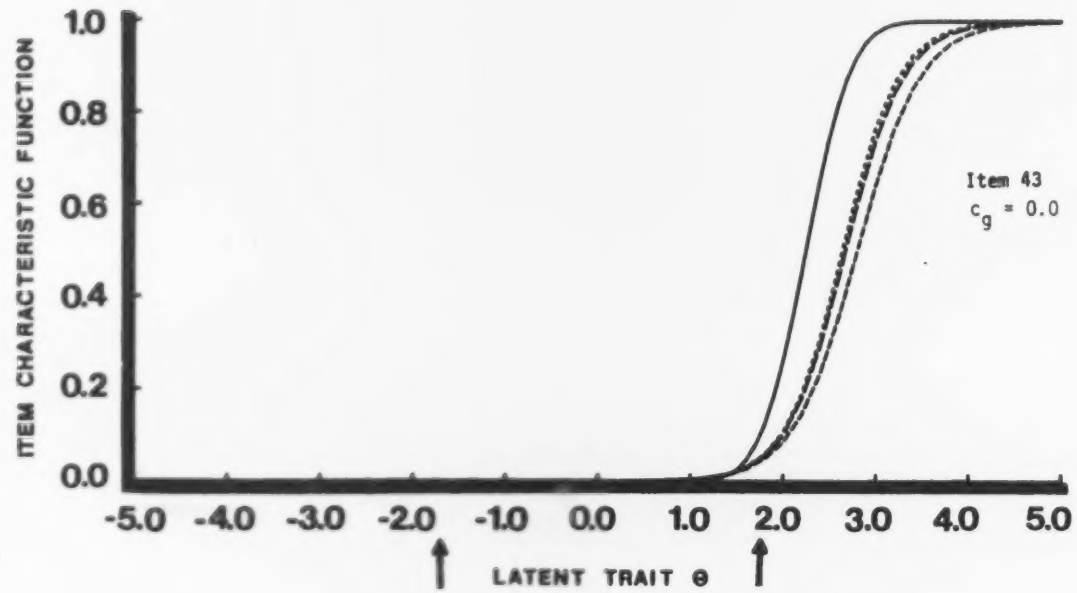


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

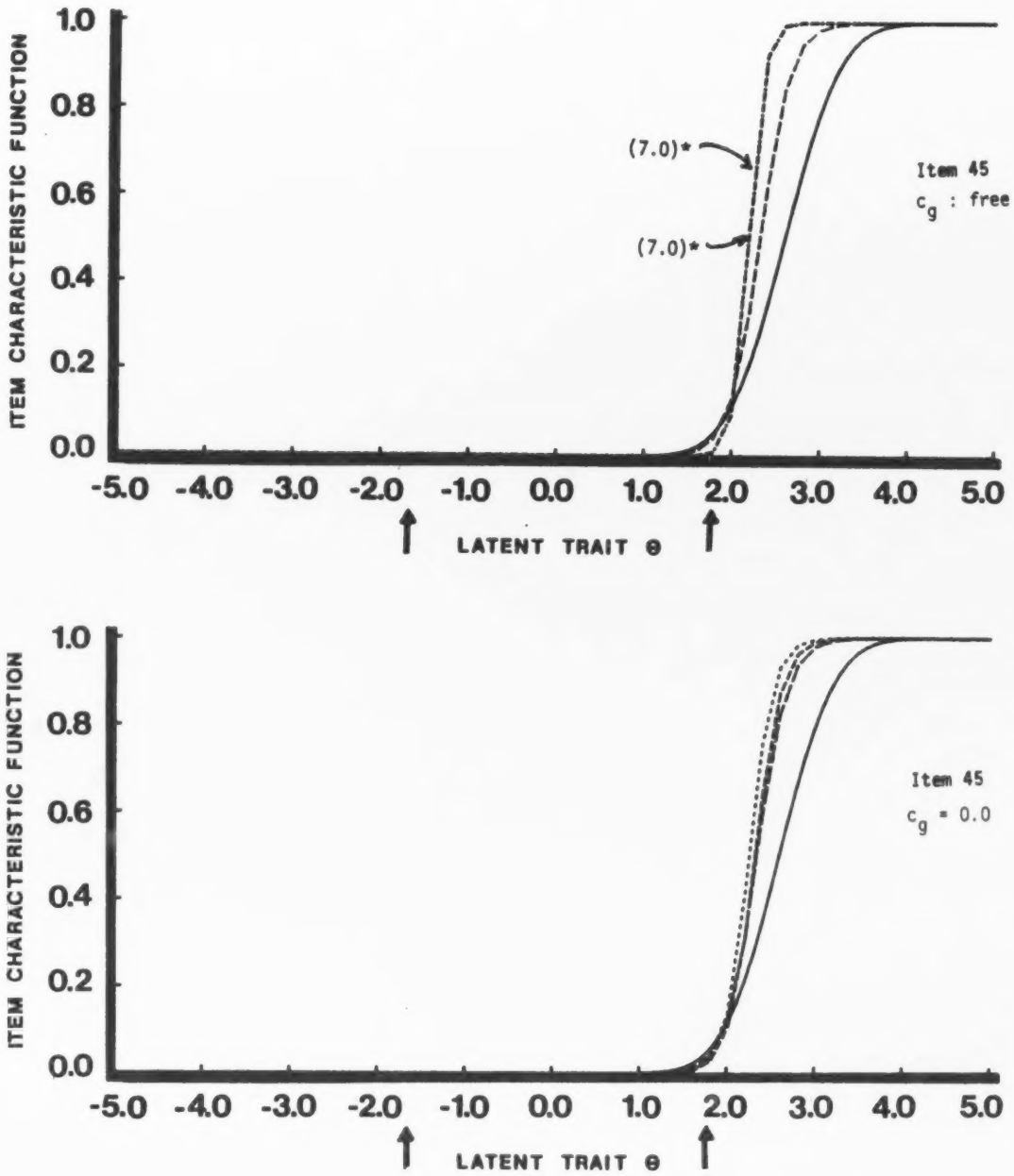


FIGURE 6-2 (Continued)

Thirty-Five Item Test, 2,000 Subject Case

5-2 for the Ten Item Test.

We find similar tendencies in these results as were observed for the items of the Ten Item Test in the preceding section. As before, there are some items which have "big tails" in the negative direction. For items 21, 25, 28, 30, 31, 32, 33, 34, 35, 36, 37 and 38, however, the results obtained by assuming the three-parameter logistic model appear to be just as good as those obtained by assuming the logistic model, both in the 500 and 2,000 Subject Cases.

VII. Discrimination Shrinkage Factor and Difficulty Reduction Index of the Three-Parameter Logistic Model

The results presented in the preceding three sections suggest that there exists a substantial effect of assuming the third parameter, c_g, on the other two estimated item parameters, when the estimation is made by "molding" the item characteristic function into that of the three-parameter logistic model, when actually it follows the normal ogive model. This effect appears to be stronger on the estimated discrimination parameter than on the estimated difficulty parameter.

Figure 7-1 presents the item characteristic function in the normal ogive model with $a_g = 1.00$ and $b_g = 0.00$ by a dotted line, the one in the logistic model with the same parameters and the scaling factor, $D = 1.7$, by a solid line, and the one in the three-parameter logistic model with the same two item parameters and scaling factor and the third parameter, $c_g = 0.25$, by a dashed

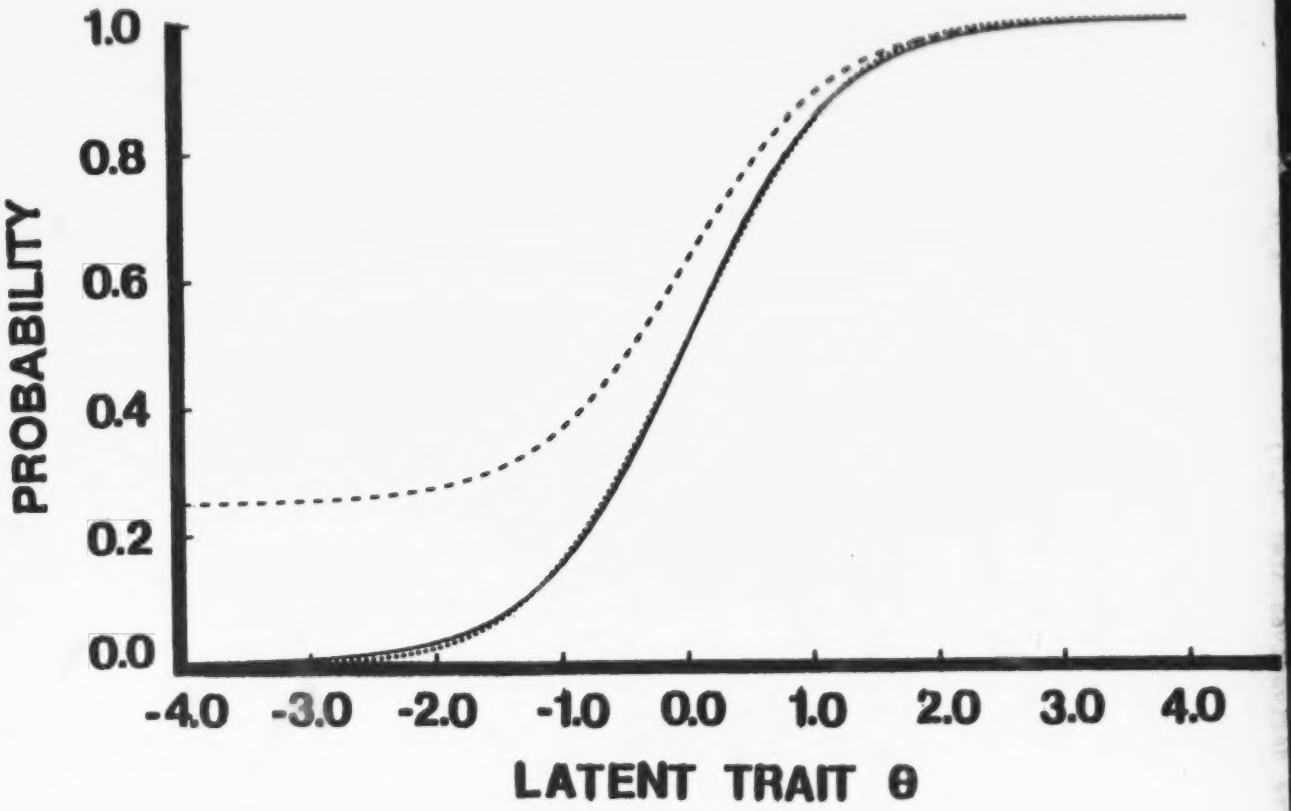


FIGURE 7-1

Item Characteristic Functions in the Normal Ogive Model (Dotted Line), In the Logistic Model (Solid Line) And in the Three-Parameter Logistic Model (Dashed Line), with the Two Common Item Parameters, $a_g = 1.00$ And $b_g = 0.00$. The Scaling Factor, $D = 1.7$, Is Used for the Last Two Functions And the Guessing Parameter, $c_g = 0.25$, Is Used for the Last Function.

line. It is obvious from theory that for all the three item characteristic functions the derivative is highest at $\theta = b_g = 0.00$. Actually, these three derivatives are: $(2\pi)^{-1/2} a_g$, $Da_g/4$ and $(1-c_g)Da_g/4$, respectively, for the three functions in Figure 7-1. The ratio of this maximal slope in the normal ogive model to the one in the logistic model is approximately 0.938687718, which is not so much less than unity. The corresponding ratio between the three-parameter logistic model and the logistic model is $(1-c_g)$, which equals 0.75 when $c_g = 0.25$, and is as low as 0.50 when $c_g = 0.50$. The ratio between the three-parameter logistic model and the normal ogive model is approximately $1.065317017(1-c_g)$, which is a little higher than $(1-c_g)$.

It is obvious from the facts described above that, when we "mold" the normal ogive model into the three-parameter logistic model and estimate the three item parameters accordingly, we tend to obtain a larger value for the estimated item discrimination parameter, in order to "fight" the effect of the guessing parameter. It is especially so when the estimated guessing parameter turns out to be a large value for one reason or another. It is also obvious from Figure 7-1 that the difficulty parameter tends to be estimated higher than it really is.

Let $P_g^*(\theta)$ be the item characteristic function in the three-parameter logistic model obtained by "molding" the one in the logistic model, which is given by (1.2). Thus we can write

$$(7.1) \qquad P_g^*(\theta) = c_g^* + (1-c_g^*)\,\Psi_g^*(\theta) \quad ,$$

where

$$(7.2) \qquad \Psi^*_g(\theta) = [1 + \exp\{-Da^*_g(\theta - b^*_g)\}]^{-1} \quad ,$$

with a^*_g (> 0) and b^*_g as the discrimination and difficulty parameters, respectively, and $D = 1.7$. It is obvious that, when $c^*_g = 0.0$, (7.1) provides us with the identical function as (1.2) if we set $a^*_g = a_g$ and $b^*_g = b_g$. When $c_g \neq 0.0$, however, there is no way to make the two functions identical, whatever values may be assigned to a^*_g and b^*_g . If we set $b^*_g = b_g$, $P^*_g(\theta)$ exceeds $\Psi_g(\theta)$ by $c^*_g/2$ at $\theta = b_g$, regardless of the value assigned to a^*_g . Thus in order to approximate $\Psi_g(\theta)$ by $P^*_g(\theta)$ we can make $P^*_g(\theta)$ equal to $\Psi_g(\theta)$ at $\theta = b^*_g$, by shifting b^*_g to the positive direction. By setting $\Psi_g(b^*_g)$ equal to $(1+c^*_g)/2$, we obtain

$$(7.3) \qquad b^*_g = b_g + \xi(c^*_g|a_g) \quad ,$$

where

$$(7.4) \qquad \xi(c^*_g|a_g) = (Da_g)^{-1} \{\log (1+c^*_g) - \log (1-c^*_g)\} \quad .$$

It is obvious from (7.4) that $\xi(c^*_g|a_g)$ is positive for all $c^*_g \neq 0.0$, and strictly increasing in c_g . This implies that $b^*_g > b_g$ for all $c^*_g \neq 0.0$, and the difference $(b^*_g - b_g)$ increases

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as c_g^* increases. It is also indicated in (7.4) that this difference increases as the true discrimination parameter a_g decreases.

We notice that, after this restriction concerning b_g^* has been made, the value of a_g^* is still free to adjust in order to make the approximation of $\Psi_g(\theta)$ by $P_g^*(\theta)$ accurate. Thus, we shall consider the value of a_g^* which makes $P_g^*(\theta)$ equal to $\Psi_g(\theta)$ at $\theta = b_g$ also. It is obvious that this can be done only when c_g is 0.5 or less, for $P_g^*(\theta)$ will never diverge $\Psi_g(\theta)$ if c_g^* is greater than 0.5 . Since any guessing parameter greater than 0.5 is absurd, this restriction is perfectly acceptable. By setting $P_g^*(b_g)$ equal to 0.5 and using b_g^* given by (7.3) and (7.4), we obtain

$$(7.5) \qquad a_g^* = \zeta(c_g^*)\, a_g \ ,$$

where

$$(7.6) \qquad \zeta(c_g^*) = \{-\log (1-2c_g^*)\}\{\log (1+c_g^*) - \log (1-c_g^*)\}^{-1} \ .$$

It is obvious from (7.6) that $\zeta(c_g^*)$ is greater than unity for all $c_g^* \neq 0$, and approaches positive infinity when c_g^* tends to 0.5 . In this limiting case where c_g approaches 0.5 , $P_g^*(\theta)$ thus obtained converges to the step function, which "jumps" from 0.5 to unity at $\theta = b_g^*$ ($\doteq b_g + 0.646242522\, a_g^{-1}$) . This implies that, if c_g^* is close to 0.5 , then $P_g^*(\theta)$ will not be very close to $\Psi_g(\theta)$

even if these two functions cross each other both at $\theta = b_g$ and at $\theta = b_g^*$, unless a_g is extremely large. When c_g is reasonably small, however, $P_g^*(\theta)$ thus obtained will provide us with a good approximation to $\Psi_g(\theta)$. Figure 7-2 presents $P_g^*(\theta)$ with varieties of different values of c_g^*, in comparison with the item characteristic functions in the logistic model and in the normal ogive model. In this example, $a_g = 1.00$ and $b_g = 0.00$ are used as the item discrimination and the item difficulty parameters of the true item characteristic function which follows the normal ogive model, and of its approximation by the logistic model. We can see in this figure that these curves representing the three-parameter logistic model with different values of c_g^* are fairly good approximations to the curves representing the normal ogive and the logistic models, for certain intervals of high values of θ, respectively. As c_g^* approaches 0.50, however, the fit becomes increasingly worse. Figure 7-3 presents those curves with the equal increment in c_g^* by 0.05, starting from $c_g^* = 0.05$. When $c_g^* = 0.50$, the curve becomes a step function with $\theta = (Da_g)^{-1} \log 3$ as the critical point. This critical value of θ equals approximately 0.64624 in the present example.

If we accept $P_g^*(\theta)$ thus obtained for a specified value of c_g as the approximation to $\Psi_g(\theta)$, or to $\Phi_g(\theta)$, the corresponding item characteristic function in the normal ogive model, then $\zeta(c_g^*|a_g)$ can be considered as the <u>difficulty reduction index</u> in the three-parameter logistic model, in the sense that the apparent difficulty parameter

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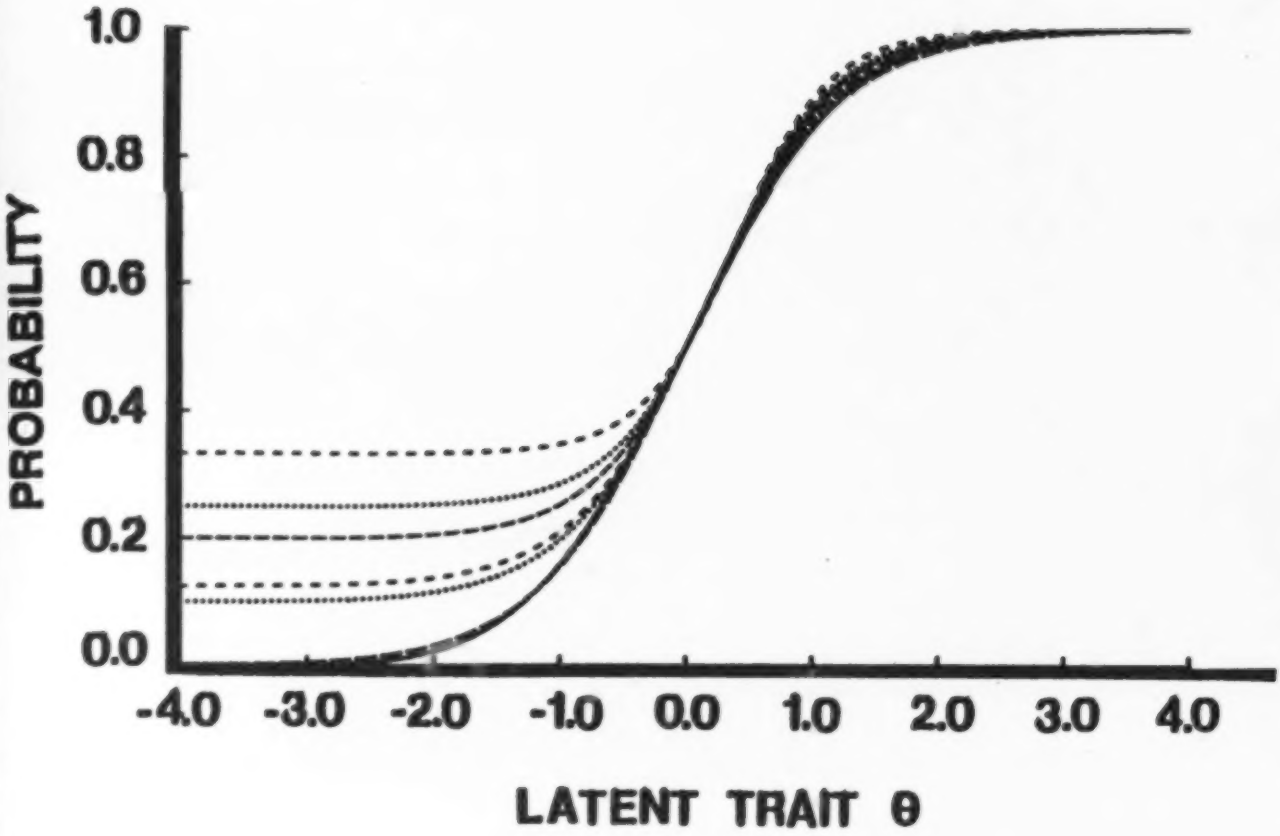

FIGURE 7-2

Item Characteristic Functions in the Three-Parameter Logistic Model with Varieties of Different Values of Guessing Parameter c_g^* , Approximating the Ones in the Normal Ogive Model (Solid Line) And in the Logistic Model (Longest Dashed Line) with the Two Common Item Parameters , $a_g = 1.00$ And $b_g = 0.00$, And the Scaling Factor, $D = 1.7$, for the Latter. The Values of c_g^* Are 1/10 , 1/8 , 1/5 , 1/4 And 1/3 .

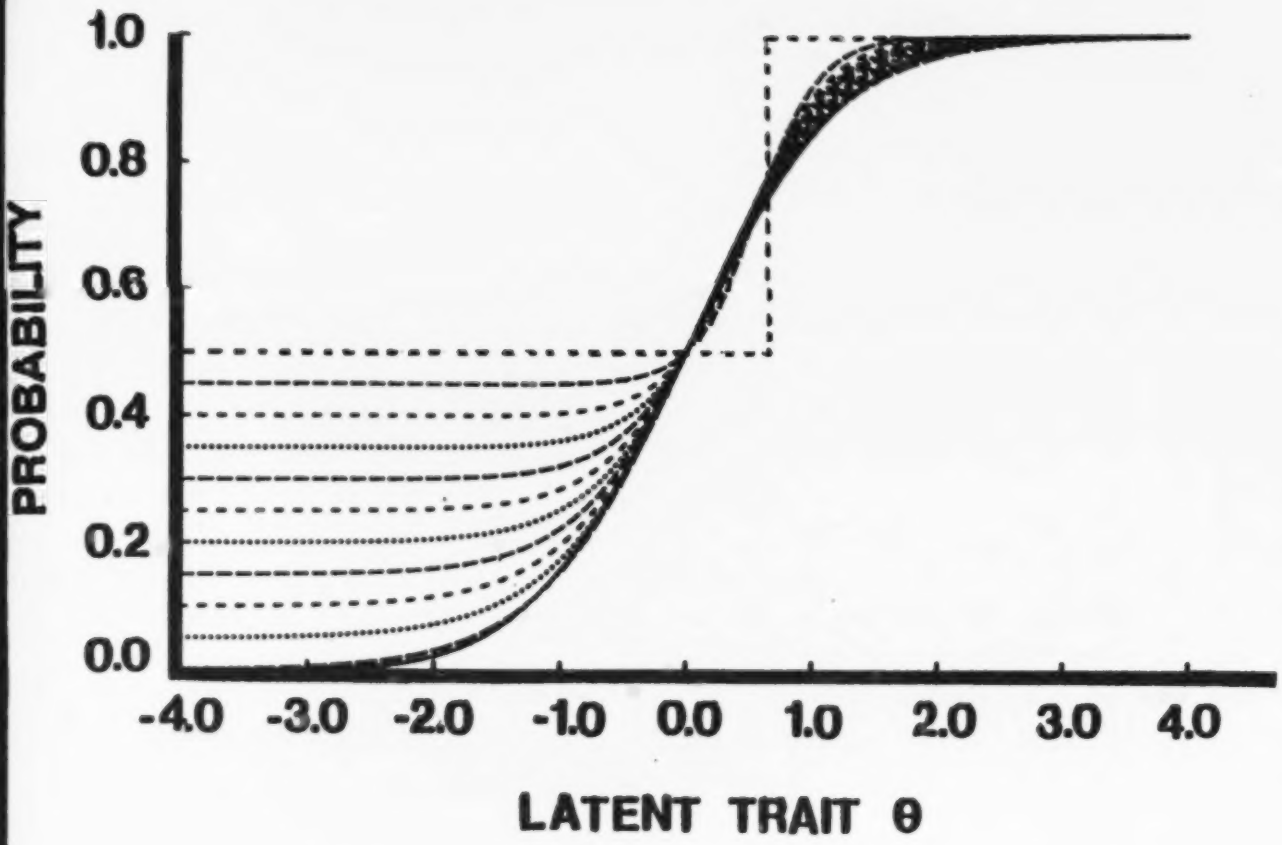

FIGURE 7-3

Item Characteristic Functions in the Three-Parameter Logistic Model with Varieties of Different Values of Guessing Parameter c_g^*, Approximating the Ones in the Normal Ogive Model (Solid Line) And in the Logistic Model (Longest Dashed Line) with the Two Common Item Parameters, $a_g = 1.00$ And $b_g = 0.00$, And the Scaling Factor, $D = 1.7$, for the Latter. The Values of c_g^* Are 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, And 0.50.

b_g^* should be reduced by this amount to reach b_g. In other words, in order to reach a fifty percent chance for success, the examinee's ability level need not be as high as b_g^*, which is usually called the difficulty parameter in the three-parameter logistic model. Note that this index is also affected by the true discrimination parameter a_g, i.e., if a_g is greater, then $\xi(c_g^*|a_g)$ is less. By the same token, the reciprocal of $\zeta(c_g^*)$ can be considered as the discrimination shrinkage factor in the three-parameter logistic model, implying that the discrimination power in the three-parameter logistic model is not as high as a_g indicates, and, in order to reach the true discrimination a_g, a_g^* needs to be multiplied by the reciprocal of $\zeta(c_g^*)$. These two functions of c_g^*, $\xi(c_g^*|a_g)$ and $\zeta(c_g^*)$, as well as the discrimination shrinkage factor, are presented for $a_g = 1.00$ in Table 7-1. The functional relationships between c_g^* and a_g^*, and between c_g^* and b_g^* when $a_g = 1.00$ and $b_g = 0.00$, are shown in Figures 7-4 and 7-5, respectively. We notice that the values of b_g^* in Figure 7-5 are also those of the difficulty reduction index $\xi(c_g^*|a_g)$ when $\theta = a_g = 1.00$. Thus for an arbitrary a_g this index is obtained as a function of c_g^* by dividing those values by a_g itself. The discrimination shrinkage factor can be obtained as the reciprocal of the values of a_g shown in Figure 7-4. It is shown as a function of c_g in Figure 7-6. We can see in these figures that, while the difficulty reduction index increases with c_g^* almost linearly with the maximal value approximately equal to $0.64624/a_g$, the discrimination shrinkage

TABLE 7-1

Discrimination Shrinkage Factor and Its Inverse, and Difficulty Reduction Index When the True Discrimination Parameter Equals 1.0 .

Item	c_g^*	Discrimination Shrinkage Factor	Inverse of Discrimination Shrinkage Factor	Difficulty Reduction Index
1	0.00000	---	---	0.00000
2	0.01000	0.99000	1.01010	0.01177
3	0.02000	0.97999	1.02041	0.02353
4	0.03000	0.96998	1.03095	0.03530
5	0.04000	0.95996	1.04171	0.04708
6	0.05000	0.94991	1.05273	0.05887
7	0.06000	0.93985	1.06400	0.07067
8	0.07000	0.92976	1.07554	0.08249
9	0.08000	0.91964	1.08738	0.09432
10	0.09000	0.90949	1.09952	0.10617
11	0.10000	0.89929	1.11199	0.11804
12	0.11000	0.88905	1.12480	0.12994
13	0.12000	0.87875	1.13798	0.14186
14	0.13000	0.86840	1.15154	0.15381
15	0.14000	0.85798	1.16552	0.16579
16	0.15000	0.84750	1.17995	0.17781
17	0.16000	0.83693	1.19484	0.18987
18	0.17000	0.82628	1.21024	0.20196
19	0.18000	0.81554	1.22618	0.21410
20	0.19000	0.80470	1.24270	0.22628
21	0.20000	0.79374	1.25985	0.23851
22	0.21000	0.78267	1.27767	0.25079
23	0.22000	0.77147	1.29623	0.26312
24	0.23000	0.76013	1.31557	0.27552
25	0.24000	0.74863	1.33578	0.28797
26	0.25000	0.73697	1.35692	0.30049
27	0.26000	0.72512	1.37908	0.31307
28	0.27000	0.71308	1.40237	0.32572
29	0.28000	0.70083	1.42689	0.33845
30	0.29000	0.68834	1.45278	0.35125
31	0.30000	0.67559	1.48018	0.36414
32	0.31000	0.66257	1.50928	0.37711
33	0.32000	0.64924	1.54027	0.39017
34	0.33000	0.63557	1.57340	0.40333
35	0.34000	0.62152	1.60895	0.41658
36	0.35000	0.60706	1.64728	0.42993
37	0.36000	0.59214	1.68879	0.44340
38	0.37000	0.57669	1.73403	0.45697
39	0.38000	0.56065	1.78363	0.47066
40	0.39000	0.54394	1.83843	0.48447
41	0.40000	0.52646	1.89949	0.49841
42	0.41000	0.50806	1.96827	0.51248
43	0.42000	0.48859	2.04670	0.52670
44	0.43000	0.46782	2.13756	0.54105
45	0.44000	0.44545	2.24494	0.55557
46	0.45000	0.42101	2.37527	0.57024
47	0.46000	0.39380	2.53938	0.58507
48	0.47000	0.36260	2.75787	0.60008
49	0.48000	0.32495	3.07741	0.61528
50	0.49000	0.27406	3.64886	0.63066

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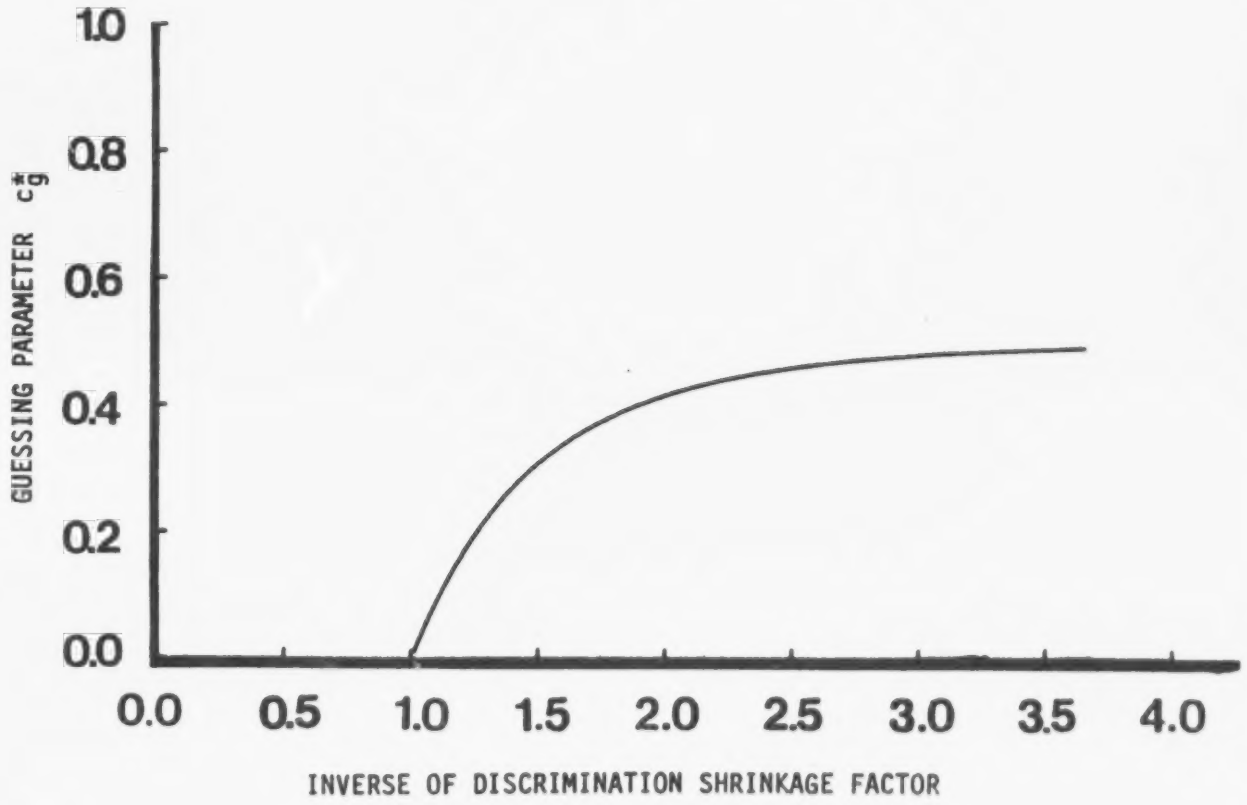

FIGURE 7-4

Functional Relationship between the "Enhanced" Discrimination Parameter a_g^* and the Guessing Parameter c_g^* When $a_g = 1.00$.

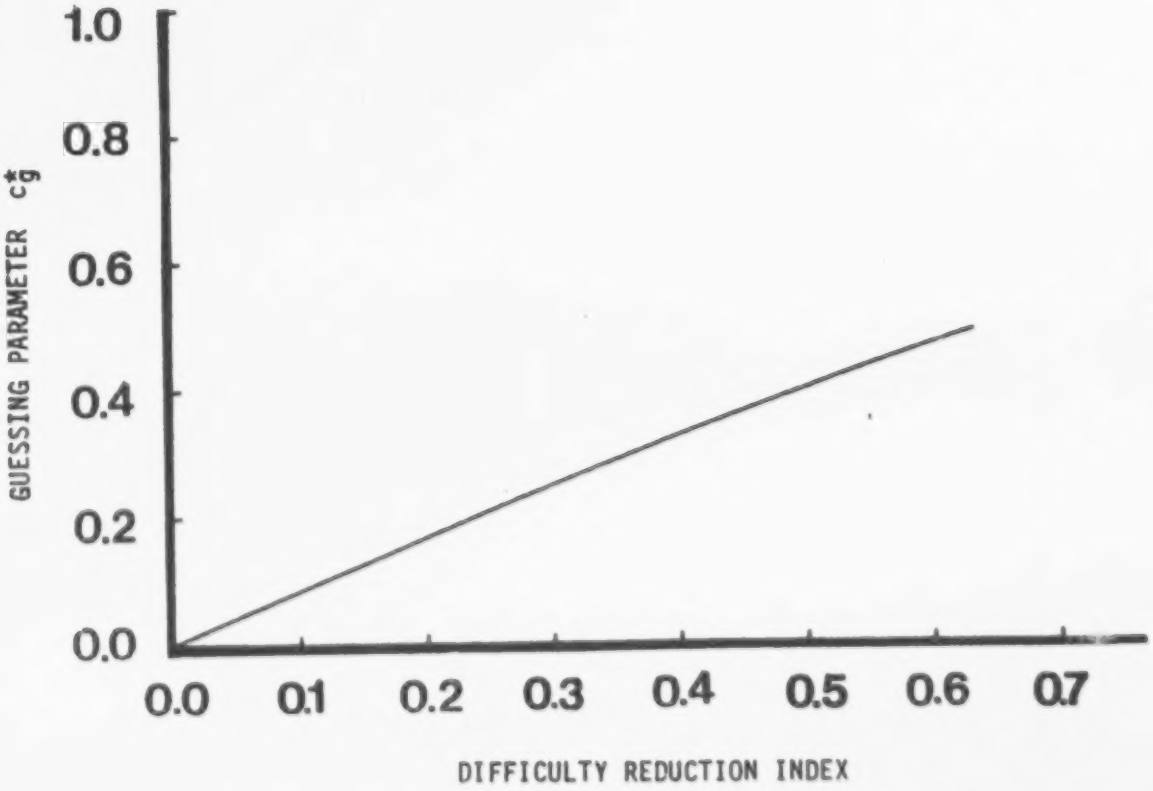

FIGURE 7-5

Functional Relationship between the "Elevated" Difficulty Parameter b_g^* and the Guessing Parameter c_g^* When $a_g = 1.00$ and $b_g = 0.00$.

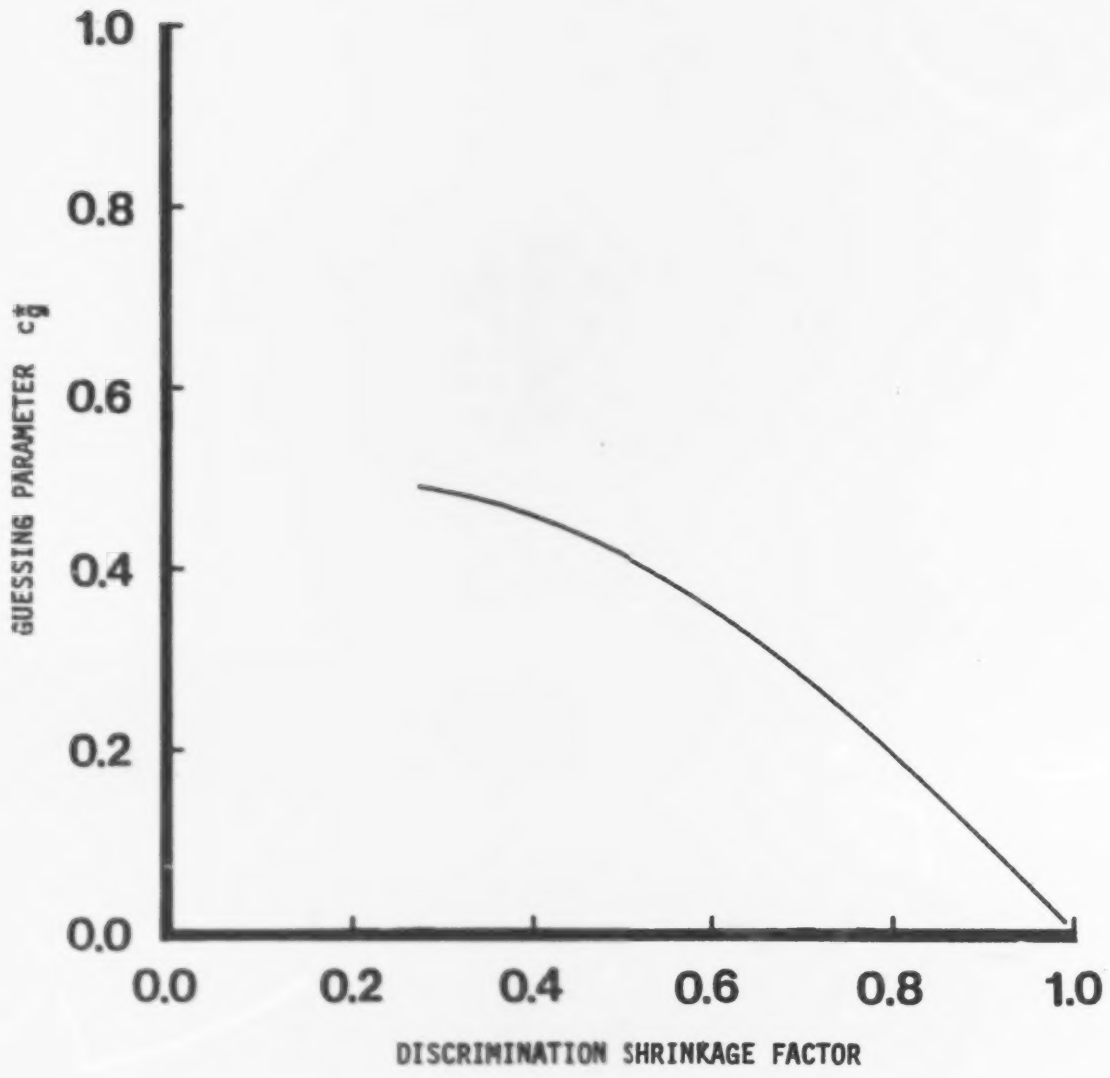

FIGURE 7-6

Discrimination Shrinkage Factor $[\, \varsigma(c_g^*) \,]^{-1}$ Plotted against the Guessing Parameter c_g^* .

factor decreases with acceleration as c_g^* approaches 0.50 .

Figure 7-7 presents the "shrunk" discrimination parameters obtained by multiplying the estimated discrimination parameter a_g^* by the discrimination shrinkage factor which was obtained by using the guessing parameter estimated by Logist 5 as c_g^* for each item. They are plotted against the theoretical a_g in the normal ogive model, for each item in Cases 1, 2, 3 and 4, in the 500 Subject Case. Comparison of these results with the first graphs of Figures 4-1 through 4-4 reveals substantial improvement. Figure 7-8 presents similar results in the 2,000 Subject Case. Improvement is even more conspicuous in these results of Figure 7-8, when compared with the first graphs of Figures 4-5 through 4-8. It is especially true for the set of forty-five items in Case 3.

The "reduced" difficulty parameters obtained by subtracting the difficulty reduction index from the estimated difficulty parameter b_g^* for each item in Cases 1, 2, 3 and 4 are plotted against the true difficulty parameter b_g in the normal ogive model, and presented as Figure 7-9 in the 500 Subject Case, and as Figure 7-10 in the 2,000 Subject Case, respectively. Comparison of these results with those in the first graphs of Figures 4-9 through 4-12 and those of Figures 4-13 through 4-16, respectively, clarifies substantial improvement in cases 3 and 4, in the results of the items whose difficulty parameters are in the interval $(-\sqrt{3}, \sqrt{3})$, in both 500 and 2,000 Subject Cases.

It is obvious that the above method of fitting the item characteristic function in the three-parameter logistic model to the

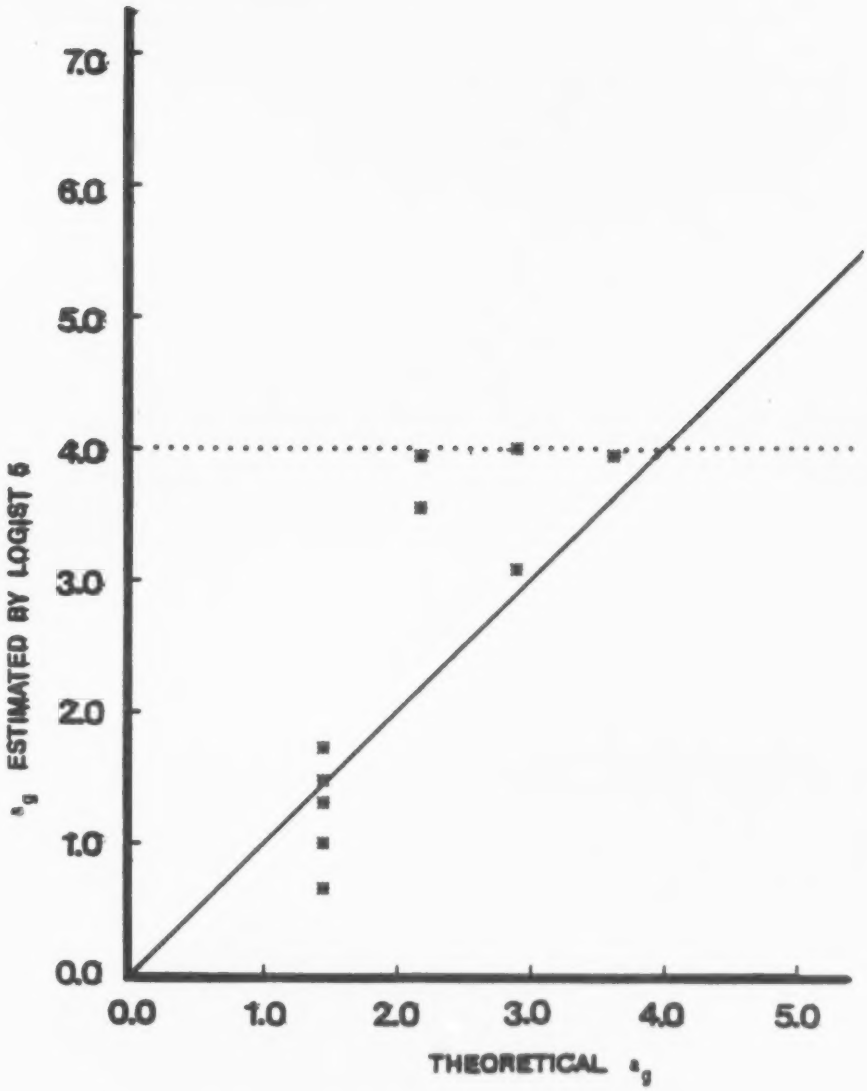

FIGURE 7-7

Scatter Diagram of the Theoretical and Estimated Item Discrimination Parameters after the Modification of the Estimated Parameters Was Made by the Discrimination Shrinkage Factor. Case 1, 500 Subject Case.

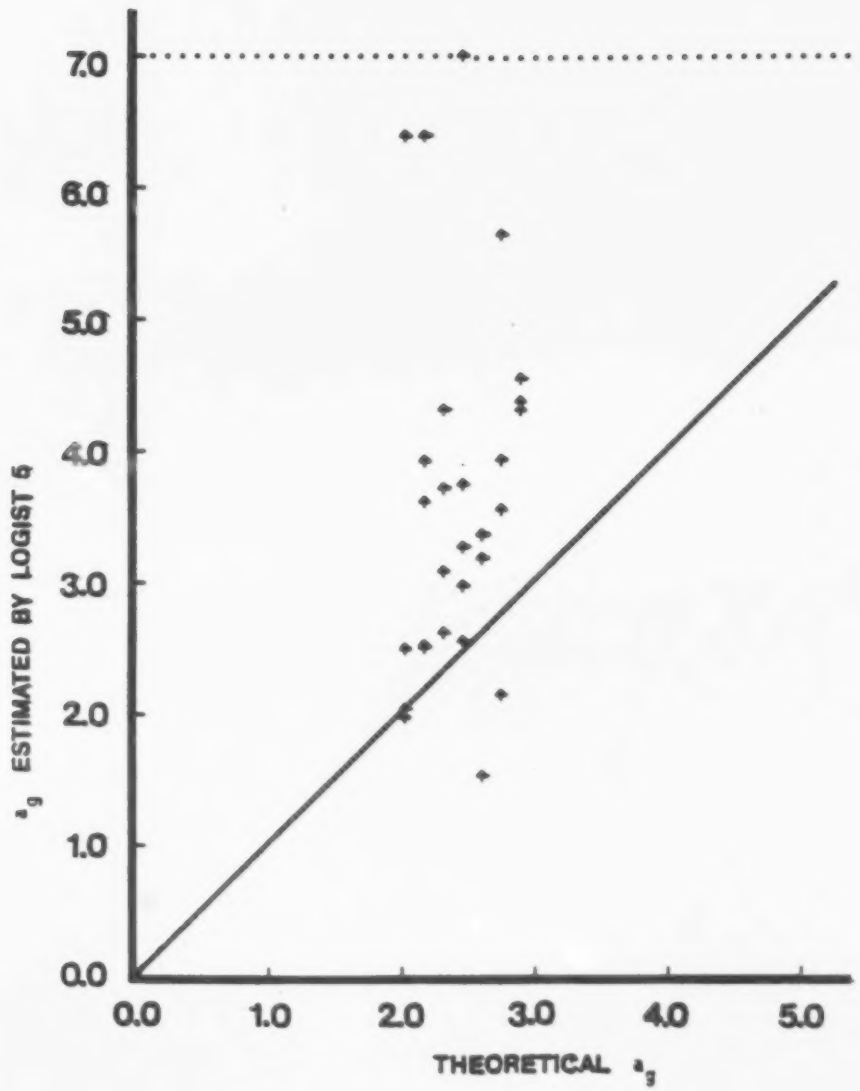

FIGURE 7-7 (Continued): Case 2, 500 Subject Case.

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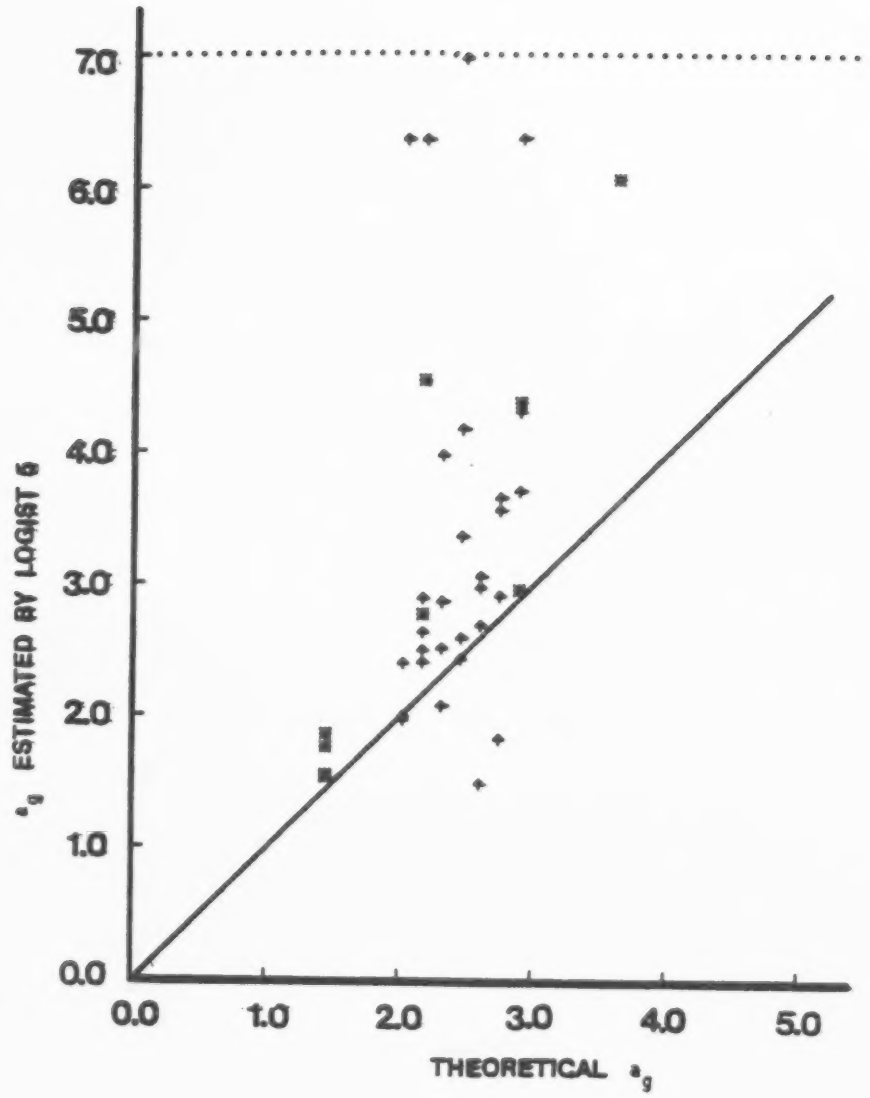

FIGURE 7-7 (Continued): Case 3, 500 Subject Case.

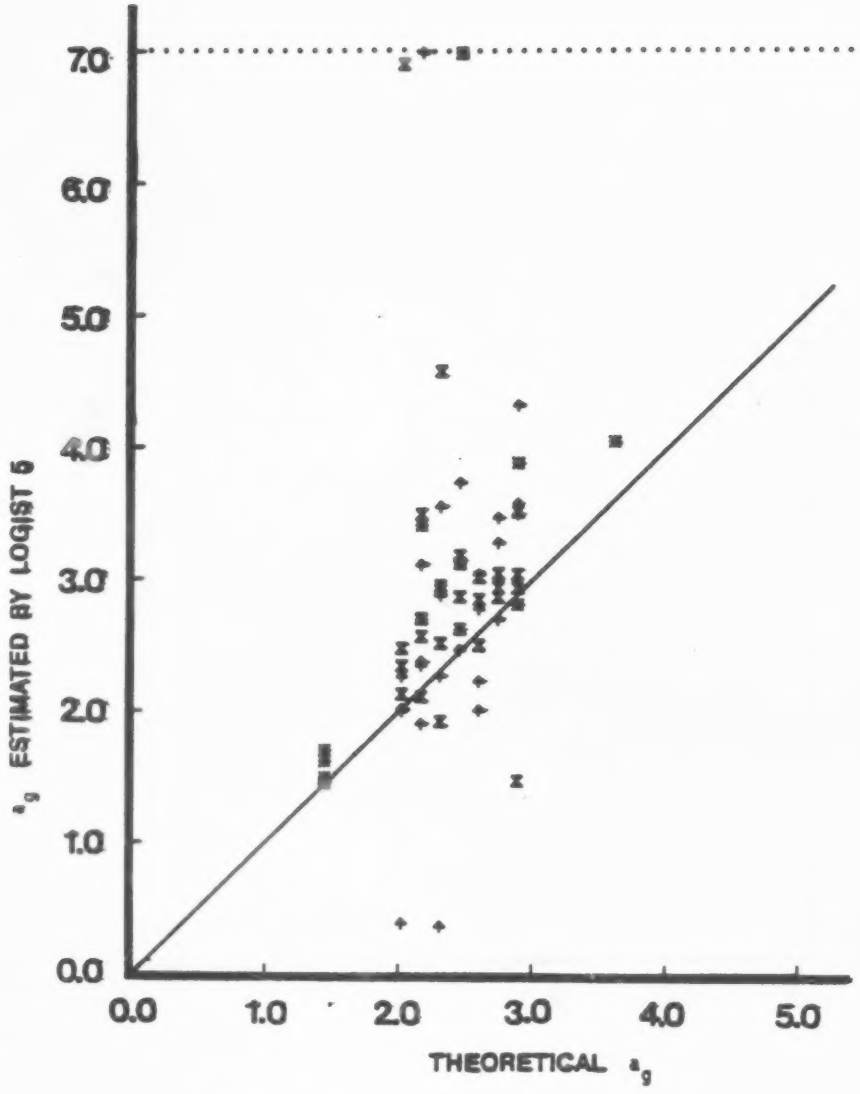

FIGURE 7-7 (Continued): Case 4, 500 Subject Case.

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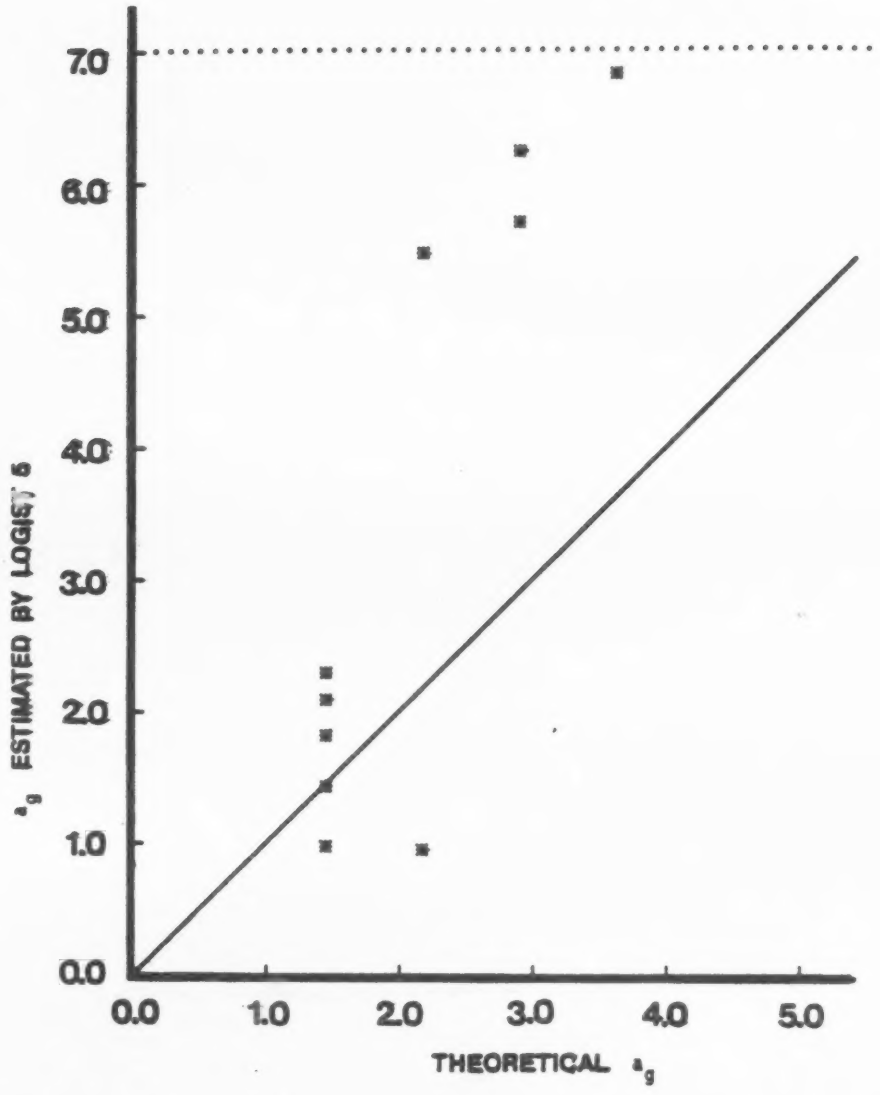

FIGURE 7-8

Scatter Diagram of the Theoretical and Estimated Item Discrimination Parameters after the Modification of the Estimated Parameters Was Made by the Discrimination Shrinkage Factor. Case 1, 2,000 Subject Case.

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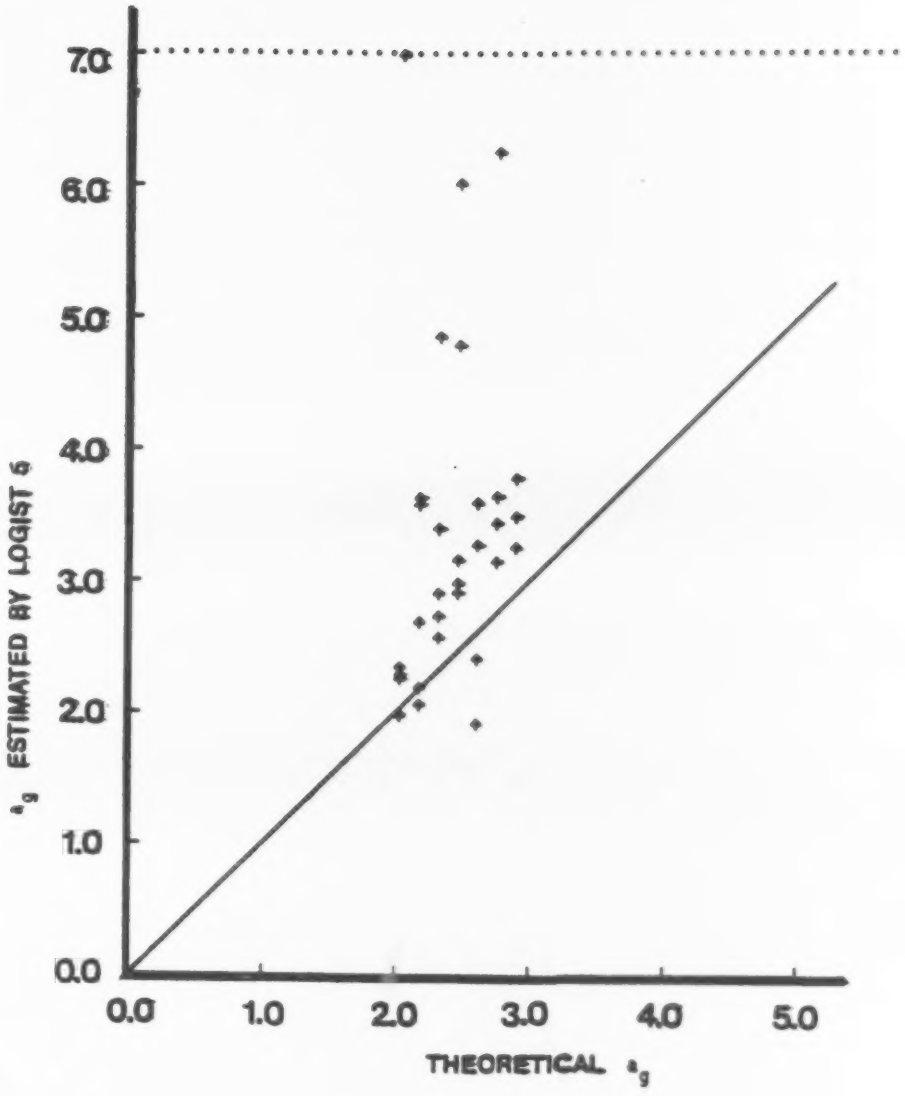

FIGURE 7-8 (Continued): Case 2, 2,000 Subject Case.

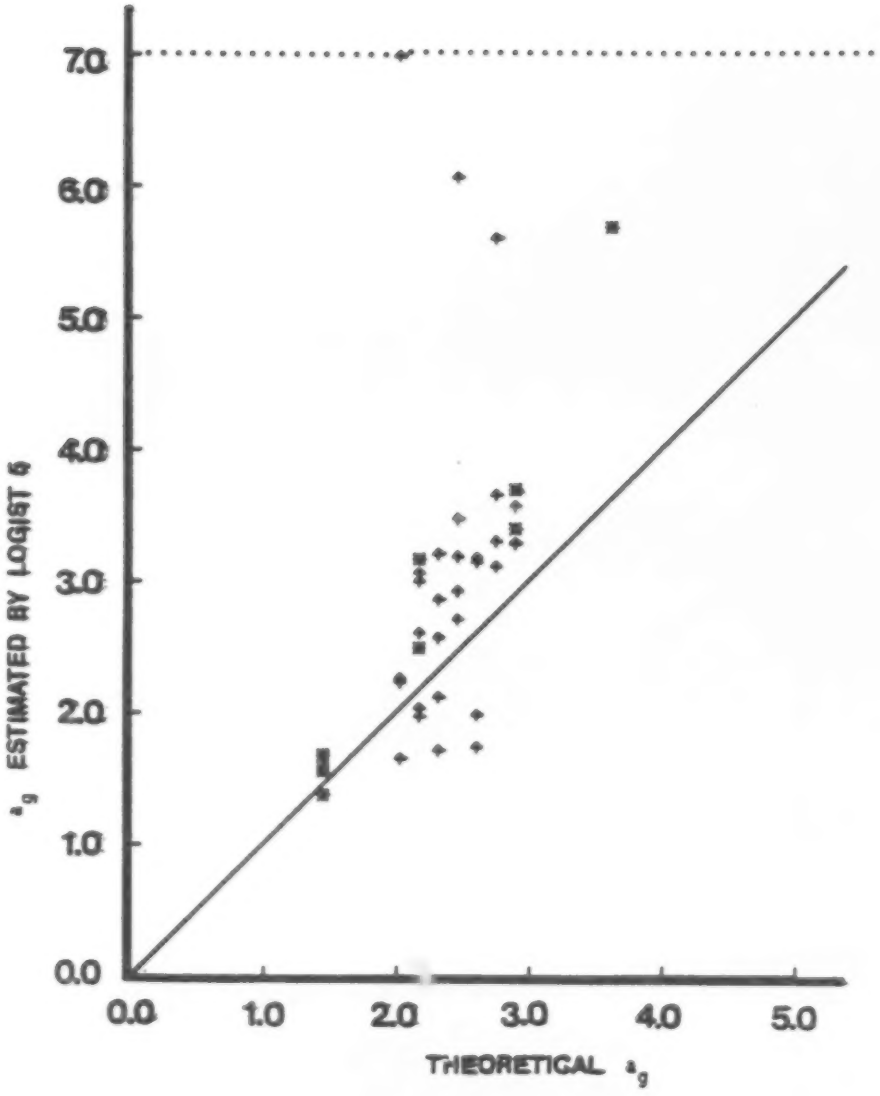

FIGURE 7-8 (Continued): Case 3, 2,000 Subject Case.

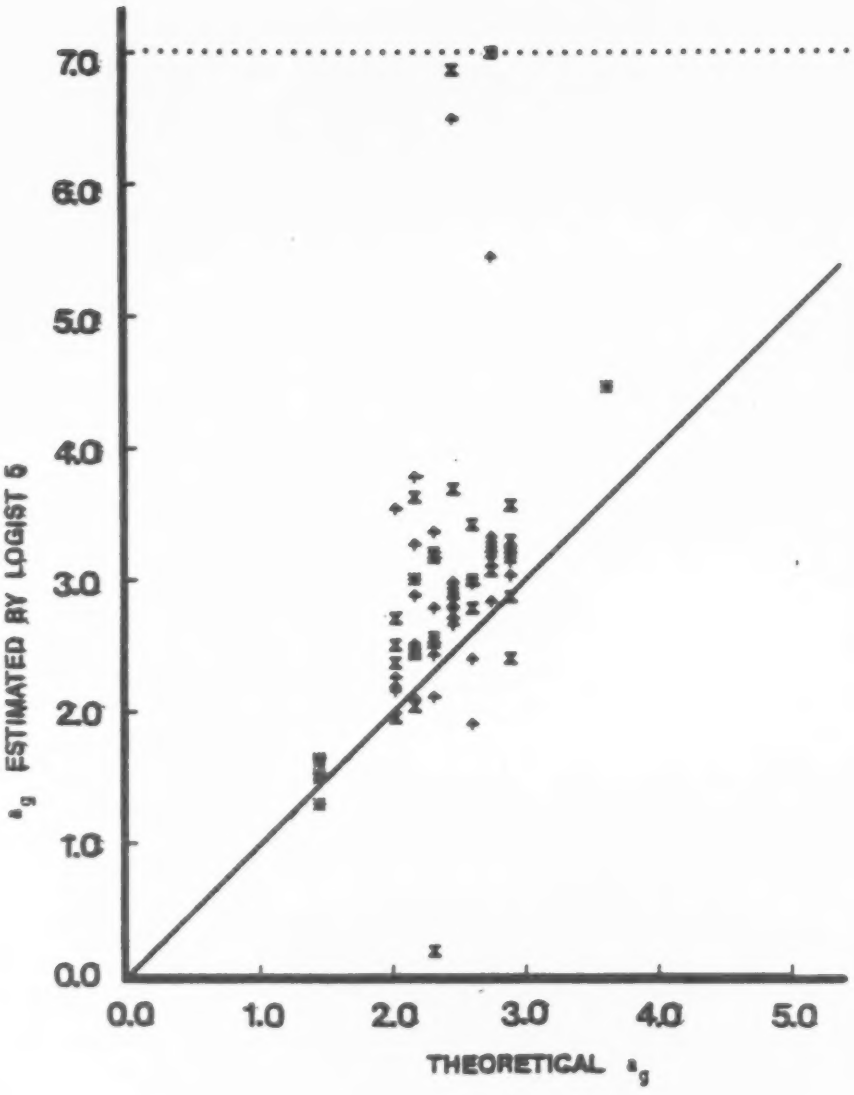

FIGURE 7-8(Continued): Case 4, 2,000 Subject Case.

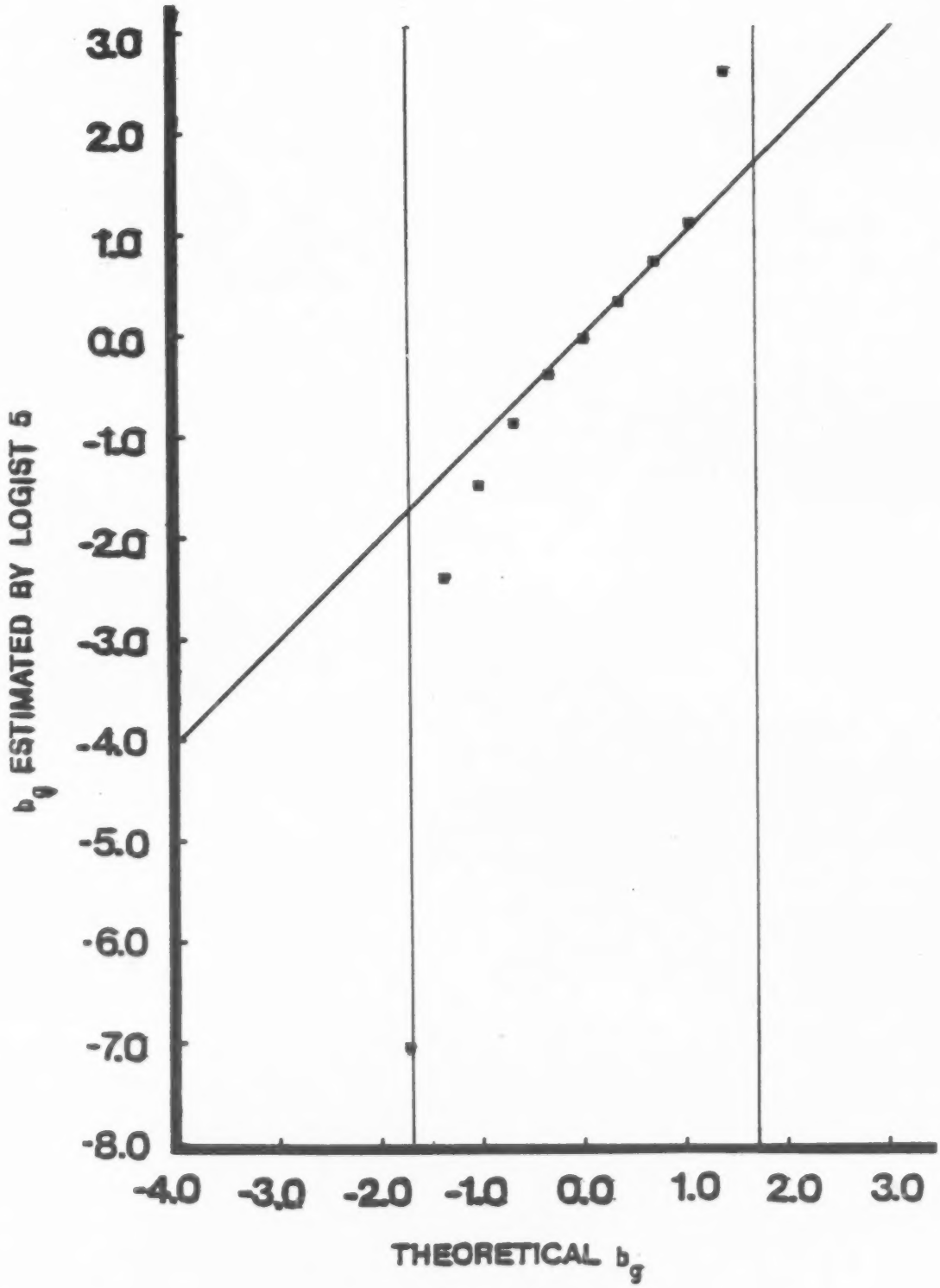

FIGURE 7-9

Estimated Item Difficulty Parameters Modified by the Difficulty Reduction Index Plotted against the Theoretical Difficulty Parameters. Case 1, 500 Subject Case.

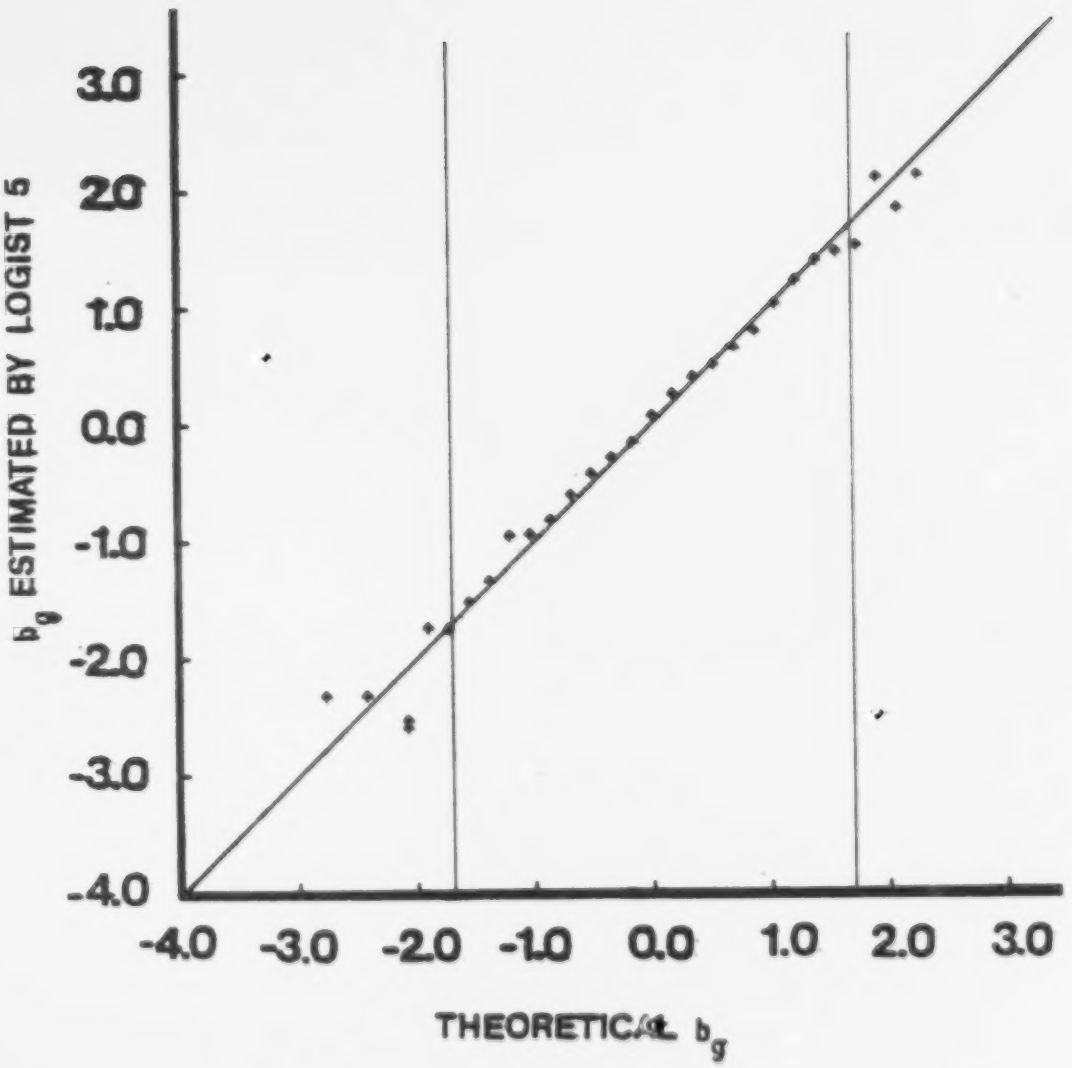

FIGURE 7-9 (Continued): Case 2, 500 Subject Case.

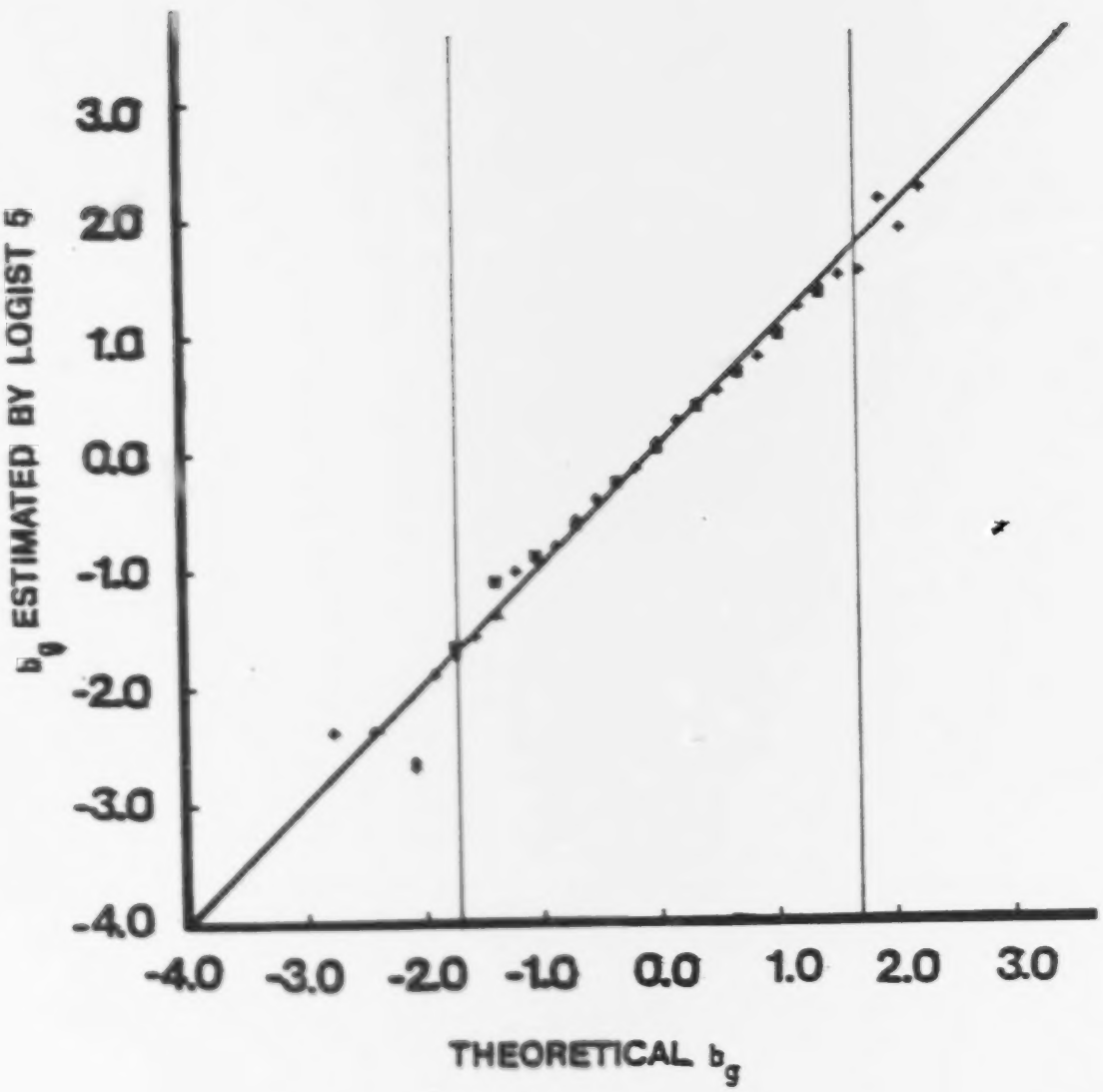

FIGURE 7-9 (Continued): Case 3, 500 Subject Case.

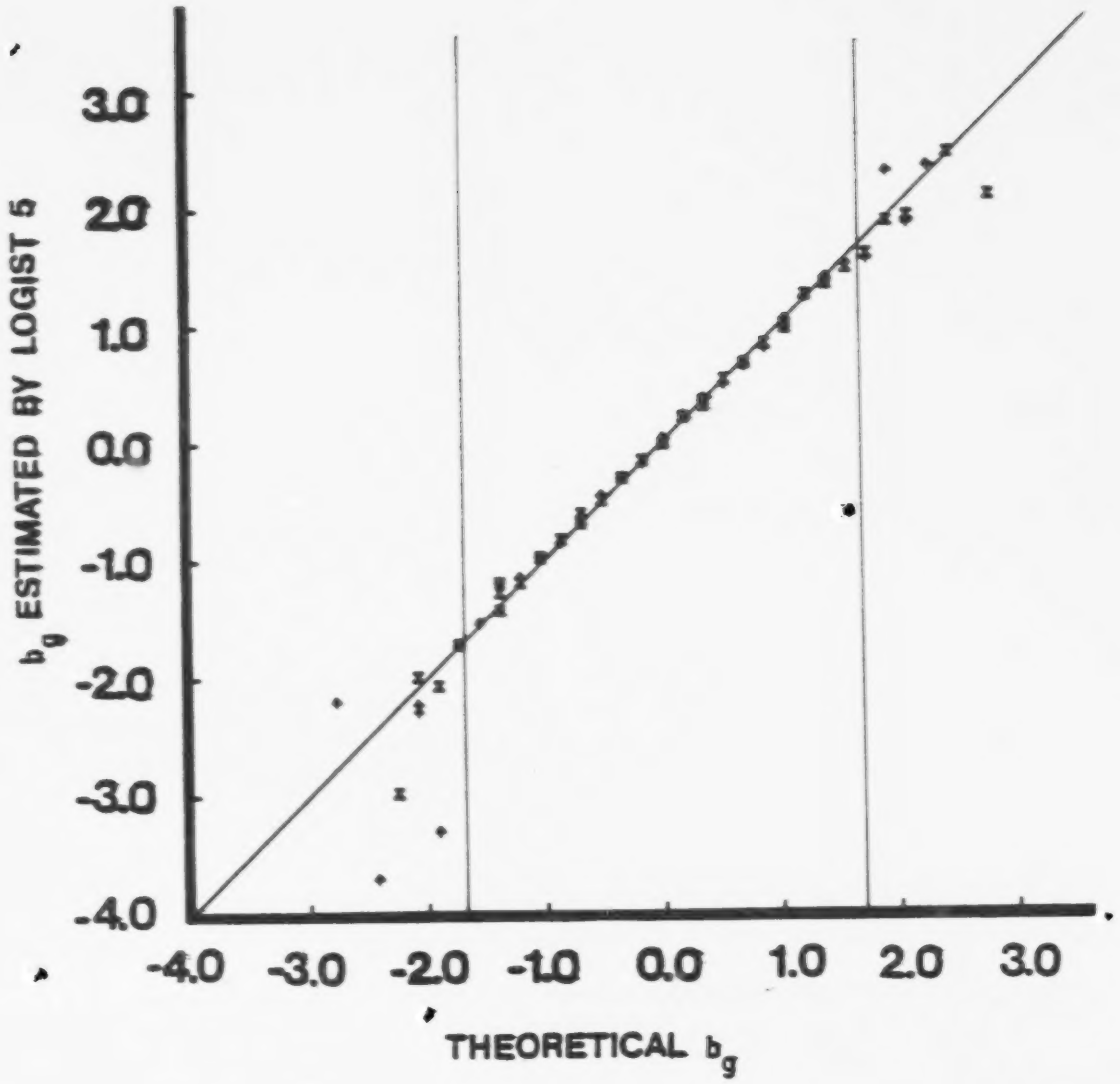

FIGURE 7-9 (Continued): Case 4, 500 Subject Case.

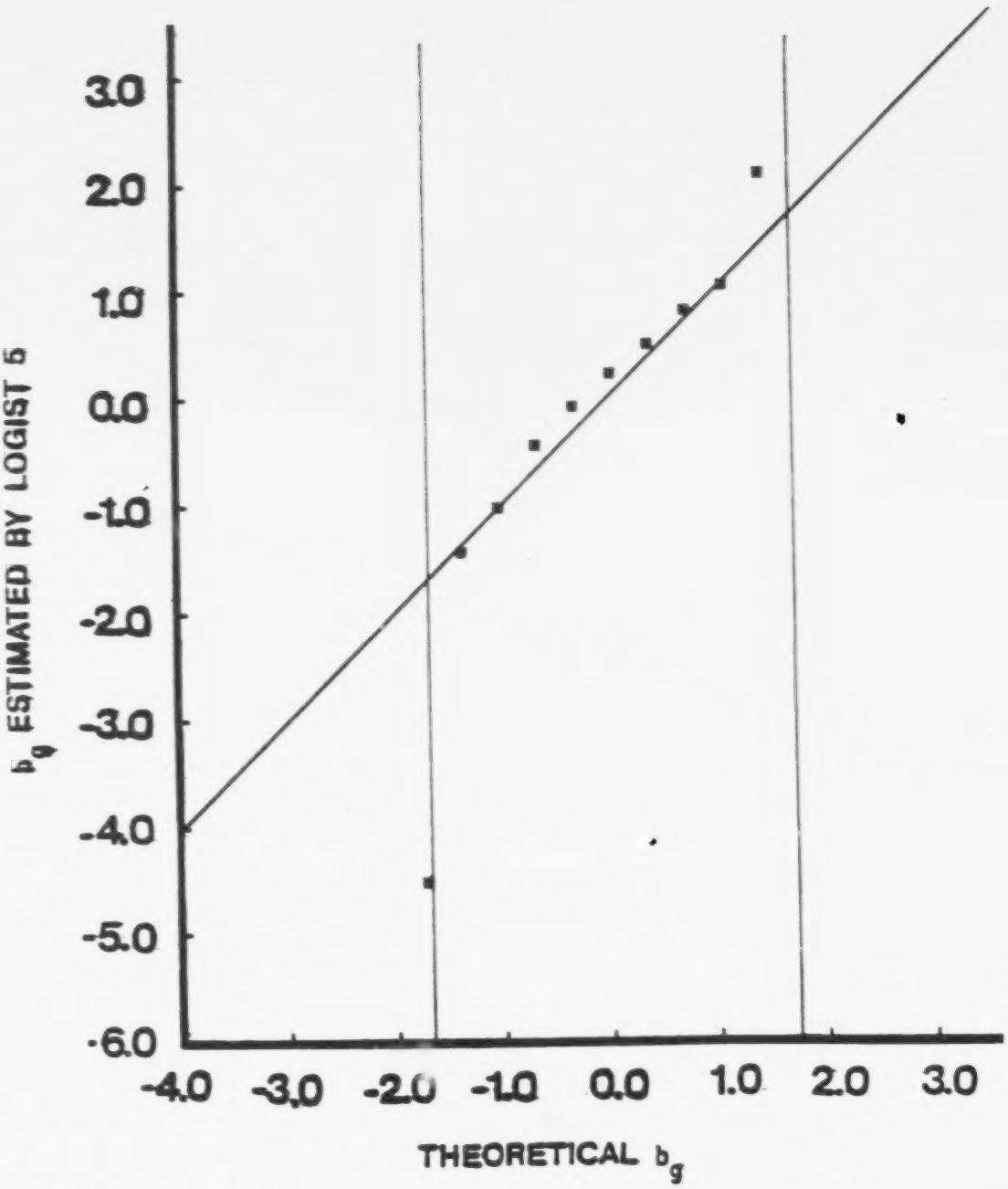

FIGURE 7-10

Estimated Item Difficulty Parameters Modified by the Difficulty Reduction Index Plotted against the Theoretical Difficulty Parameters. Case 1, 2,000 Subject Case.

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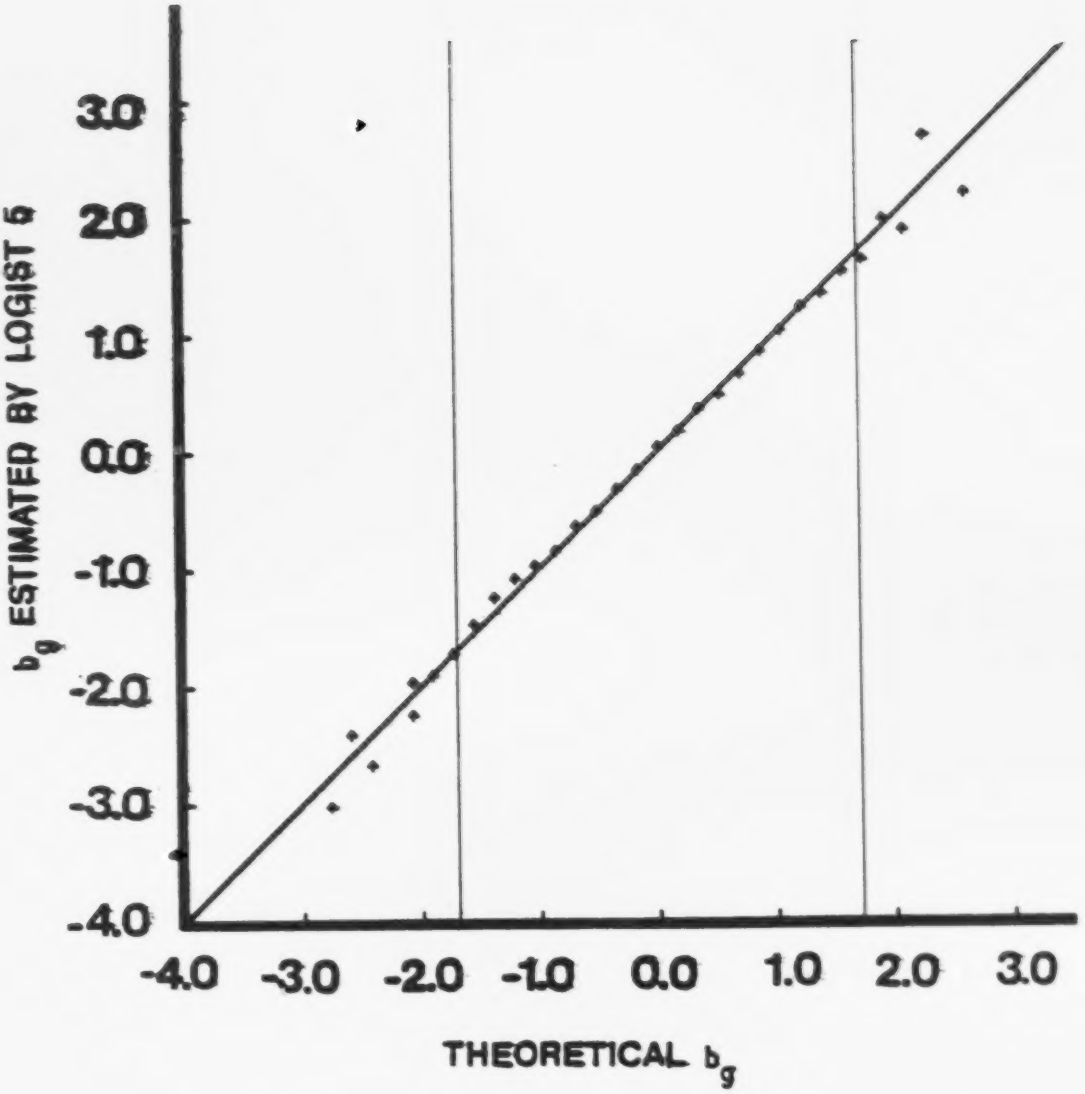

FIGURE 7-10 (Continued): Case 2, 2,000 Subject Case.

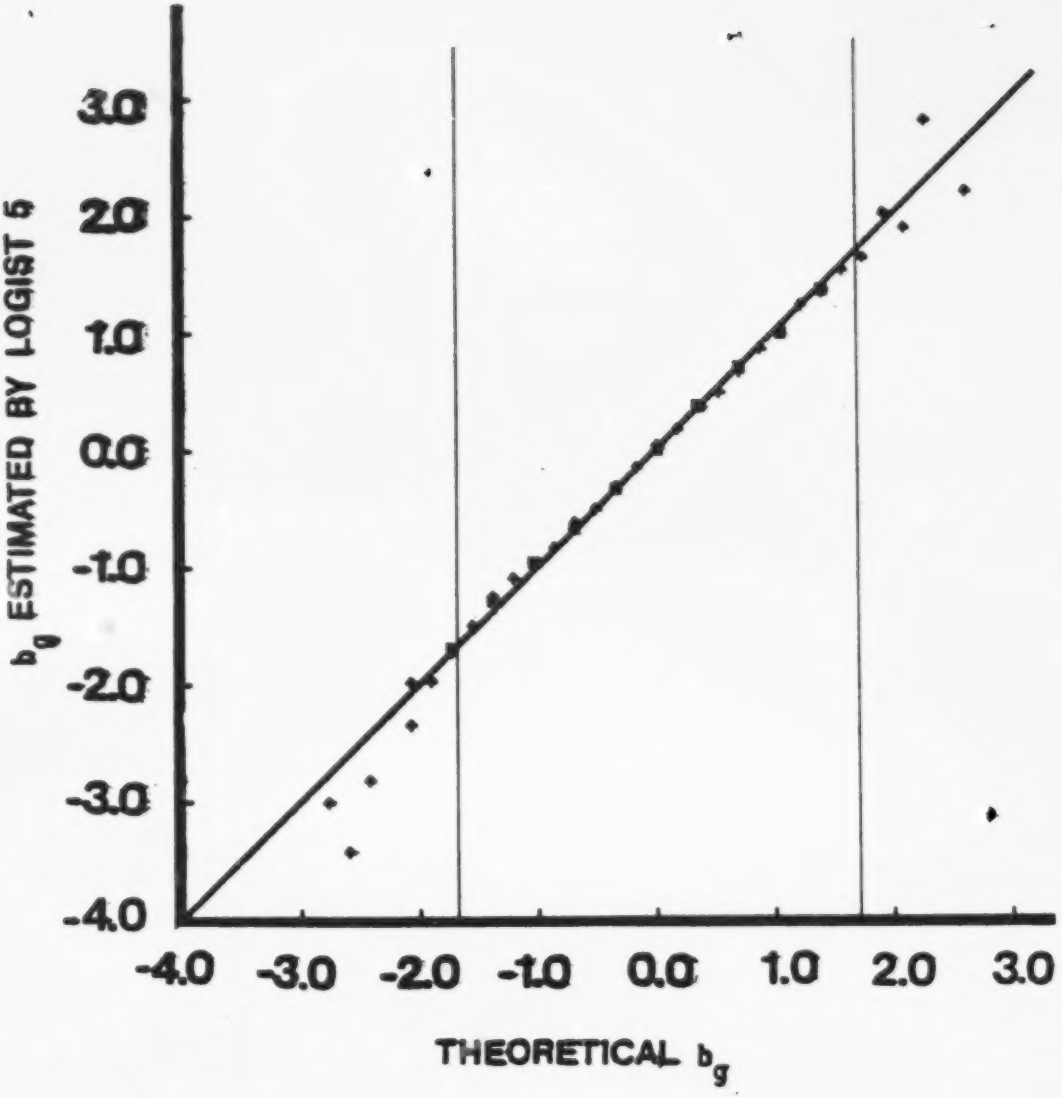

FIGURE 7-10 (Continued): Case 3, 2,000 Subject Case.

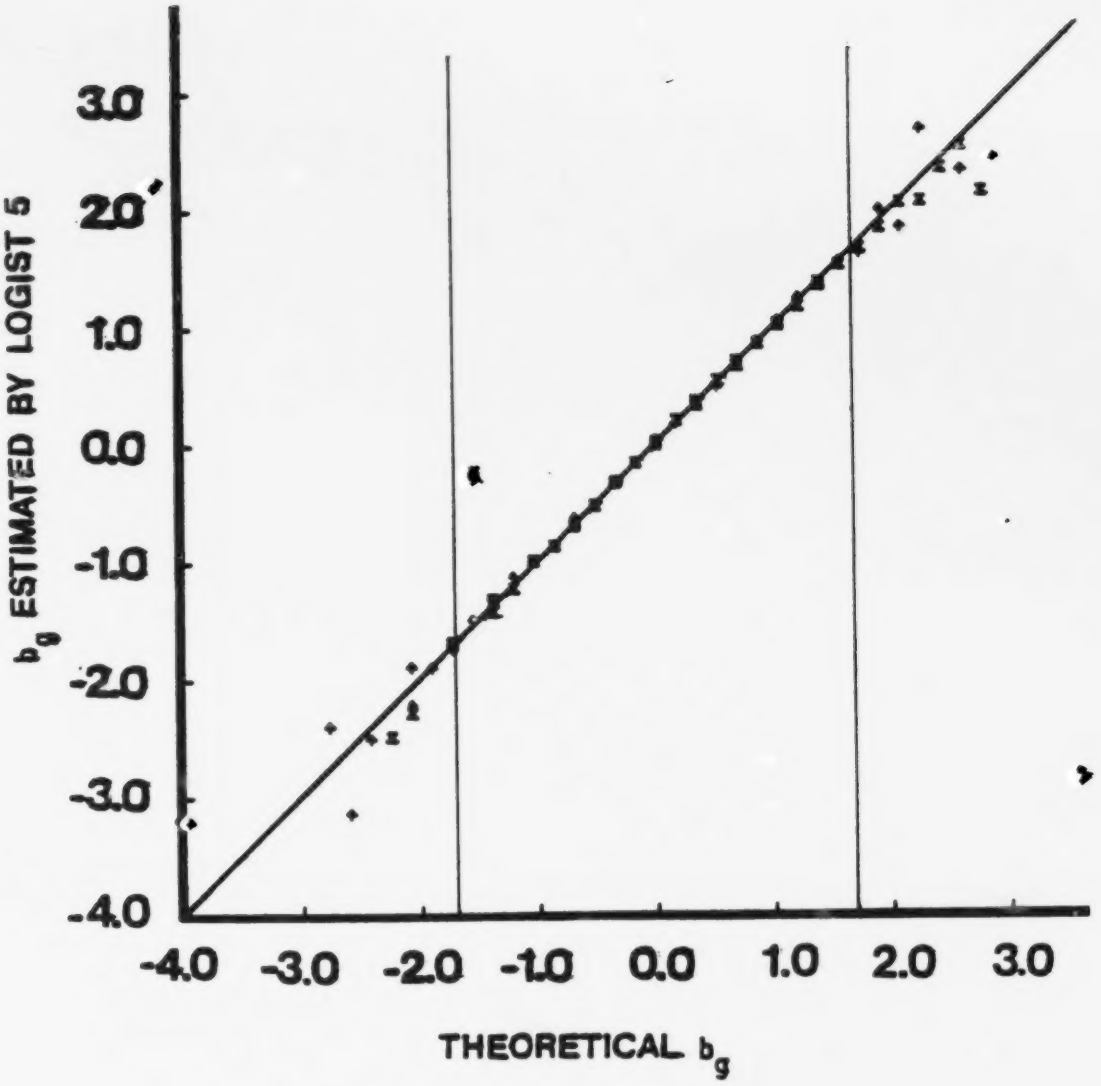

FIGURE 7-10 (Continued): Case 4, 2,000 Subject Case.

one in the (two-parameter) logistic model is more or less arbitrary. There are many other conceivable methods. If, for instance, we adopt the least squares principle to minimize

$$2Q = \int_{\underline{\theta}}^{\bar{\theta}} [P_g^*(\theta) - \Psi_g(\theta)]^2 \, d\theta \quad , \tag{7.7}$$

where $\underline{\theta}$ and $\bar{\theta}$ are the lower and upper endpoints of the interval of θ for which the integral of the squared discrepancies between $P_g^*(\theta)$ and $\Psi_g(\theta)$ is minimized, then we obtain

$$\int_{\underline{\theta}}^{\bar{\theta}} [P_g^*(\theta)-\Psi_g(\theta)](\theta-b_g^*)\Psi_g^*(\theta)[1-\Psi_g^*(\theta)] \, d\theta = 0 \tag{7.8}$$

and

$$\int_{\underline{\theta}}^{\bar{\theta}} [P_g^*(\theta)-\Psi_g(\theta)]\Psi_g^*(\theta)[1-\Psi_g^*(\theta)] \, d\theta = 0 \tag{7.9}$$

as the simultaneous equations for solving a_g^* and b_g^* when c_g^* is given. We could obtain the estimates of a_g^* and b_g^* by using an iterative procedure based upon (7.8) and (7.9) by choosing an appropriate interval $(\underline{\theta}, \bar{\theta})$. The process is expected to be tedious, however.

Another conceivable way is to find out $P_g^*(\theta)$ which equals $\Psi_g(\theta)$ at $\theta = b_g$, and also whose derivative with respect to θ equals that of $\Psi_g(\theta)$ at the same point of θ. Thus we can write

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$$(7.10)\qquad \begin{cases} P_g^*(\theta) = \Psi_g(\theta) = 1/2 \\ \\ \dfrac{\partial}{\partial\theta} P_g^*(\theta) = \dfrac{\partial}{\partial\theta} \Psi_g(\theta) = Da_g/4 \end{cases}$$

for $\theta = b_g$. Since we have

$$(7.11)\qquad \Psi_g^*(b_g) = (1-2c_g^*)[2(1-c_g^*)]^{-1} \quad ,$$

we obtain from this, (7.2) and (7.10)

$$(7.12)\qquad a_g^* = \zeta^*(c_g^*)\, a_g$$

and

$$(7.13)\qquad b_g^* = b_g + \xi^*(c_g^* | a_g) \quad ,$$

where

$$(7.14)\qquad \zeta^*(c_g^*) = (1-c_g^*)/\, 2(1-c_g^*) > 1$$

and

$$(7.15)\qquad \xi^*(c_g^* | a_g) = (Da_g)^{-1}(1-2c_g^*)(1-c_g^*)^{-1} - \log(1-2c_g^*) > 0 \quad .$$

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Thus we can think of the reciprocal of (7.14) as a second discrimination shrinkage factor and (7.15) as a second difficulty reduction index. Figures 7-11 through 7-13 present the relationships between c_g^* and a_g^* given by (7.12) when $a_g = 1.00$; between c_g^* and b_g^* given by (7.13) when $a_g = 1.00$ and $b_g = 0.00$, which equals the second difficulty reduction index multiplied by a_g ; and between c_g^* and the second discrimination shrinkage factor obtained as the reciprocal of (7.14), respectively. We can see a substantial difference between this second difficulty reduction index and the first one, which is presented in Figure 7-5.

Figures 7-14 and 7-15 present the item characteristic functions in the three-parameter logistic model obtained by using a_g^* and b_g^* for $a_g = 1.00$ and $b_g = 0.00$, which are given by (7.12) and (7.13), for the same two sets of c_g^* used in Figures 7-2 and 7-3, respectively, together with the corresponding item characteristic functions in the normal ogive model and in the logistic model. Comparison of the results in Figures 7-14 and 7-15 with those in Figures 7-2 and 7-3 reveals that the fit of the item characteristic functions in the three-parameter logistic model to those in the normal ogive model and in the logistic model is not as good as before, especially for the values of c_g^* greater than, or equal to, 0.2 .

VIII. Estimated Individual Parameters

Figures 8-1 through 8-4 present the estimated individual parameters plotted against the true individual parameters θ_s in

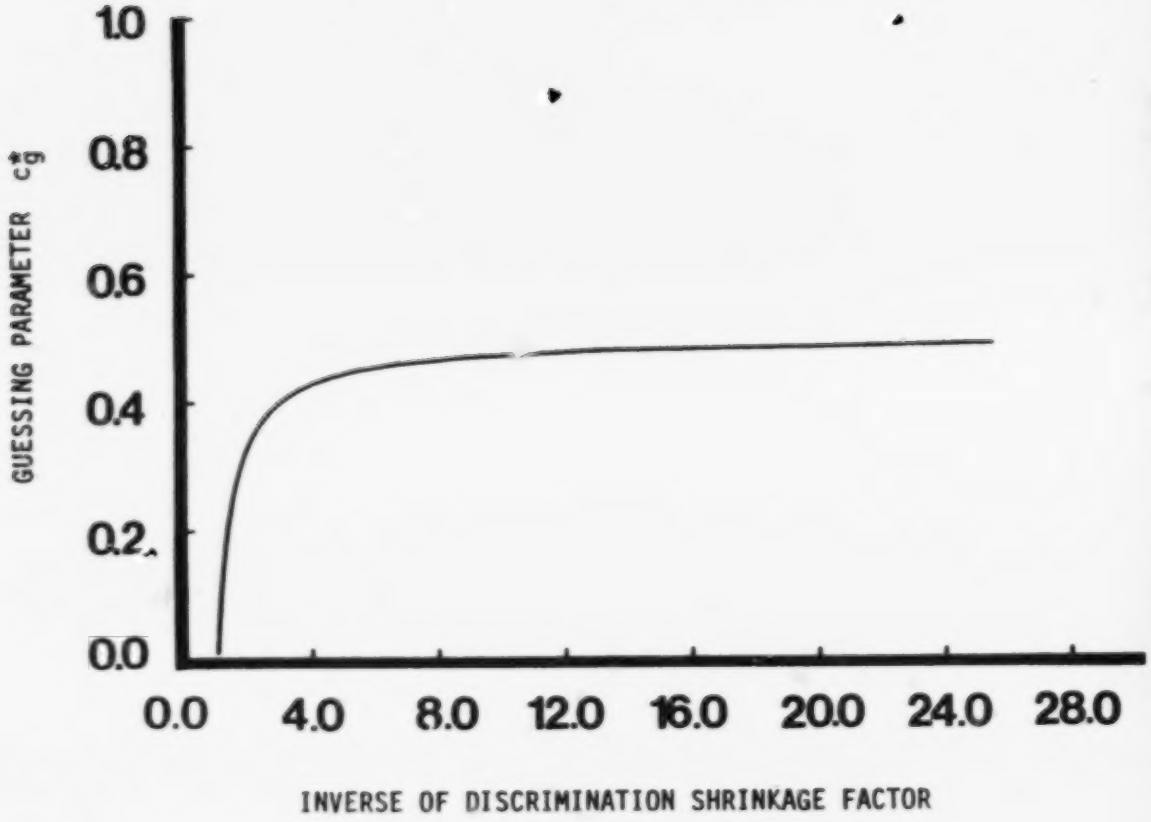

FIGURE 7-11

Functional Relationship between the "Enhanced" Discrimination Parameter a_g^* And the Guessing Parameter c_g^* When $a_g = 1.00$, Obtained by Using the Second Fitting Method.

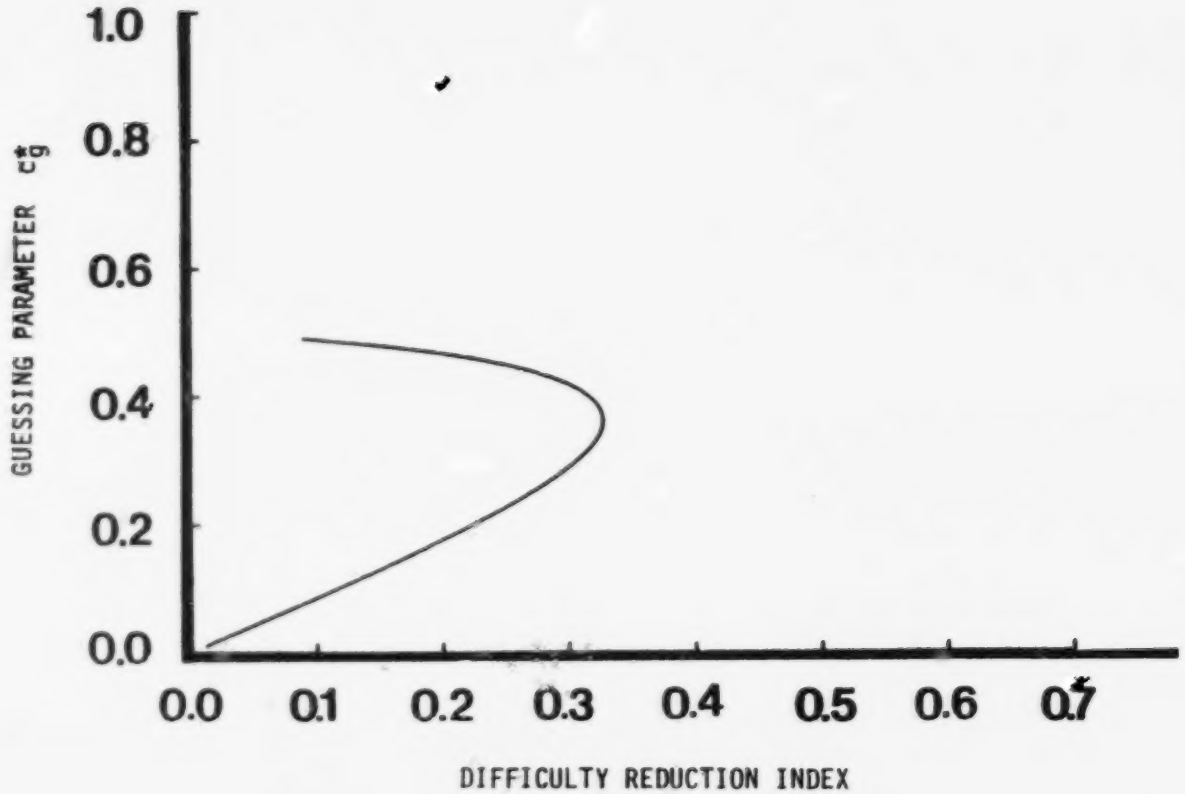

FIGURE 7-12

Functional Relationship between the "Elevated" Difficulty Parameter b_g^* And the Guessing Parameter c_g^* When $a_g = 1.00$ and $b_g = 0.00$, Obtained by Using the Second Fitting Method.

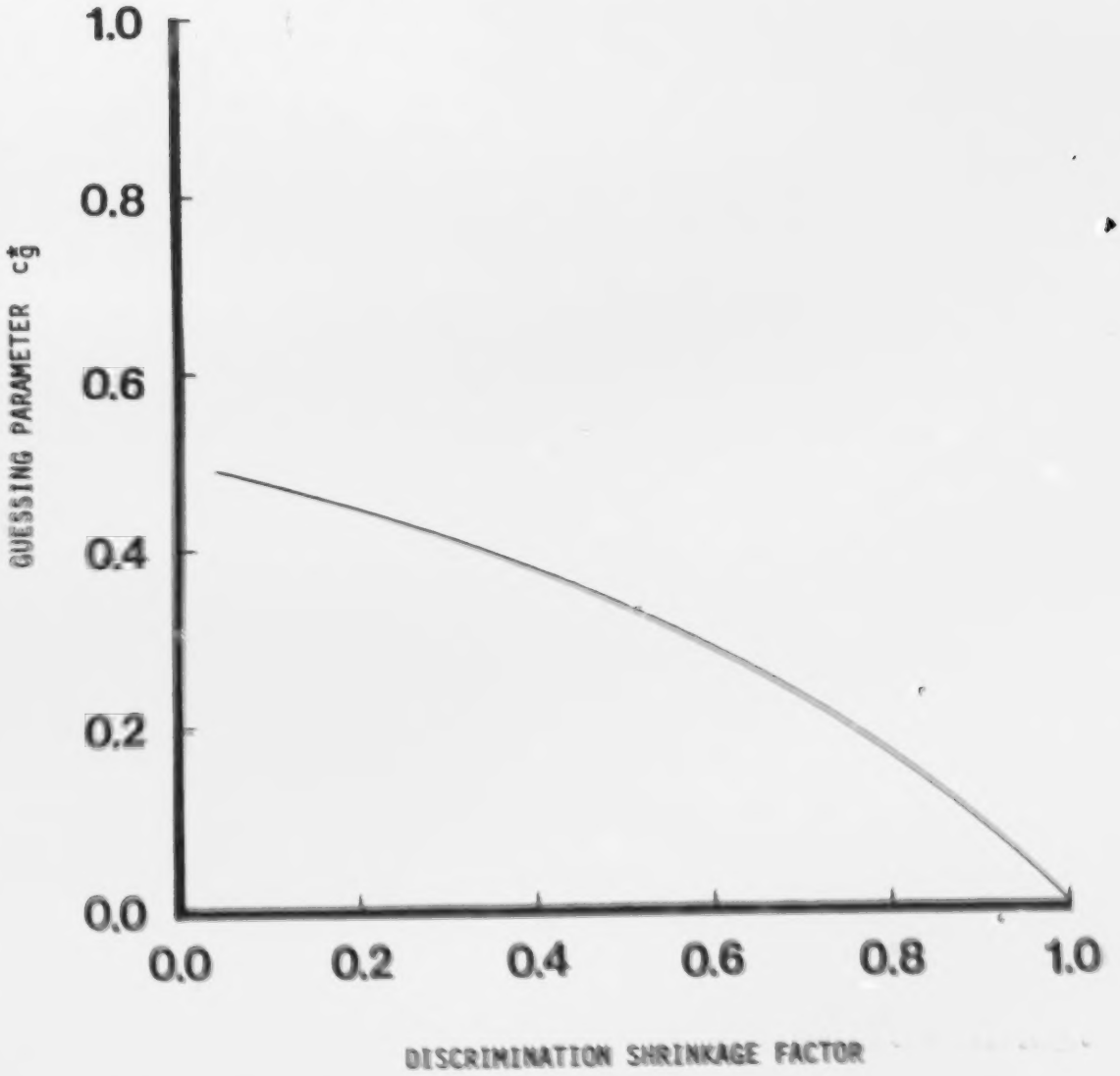

FIGURE 7-13

Discrimination Shrinkage Factor $[c(c_g^*)]^{-1}$ Plotted against the Guessing Parameter c_g^*, Obtained by Using the Second Fitting Method.

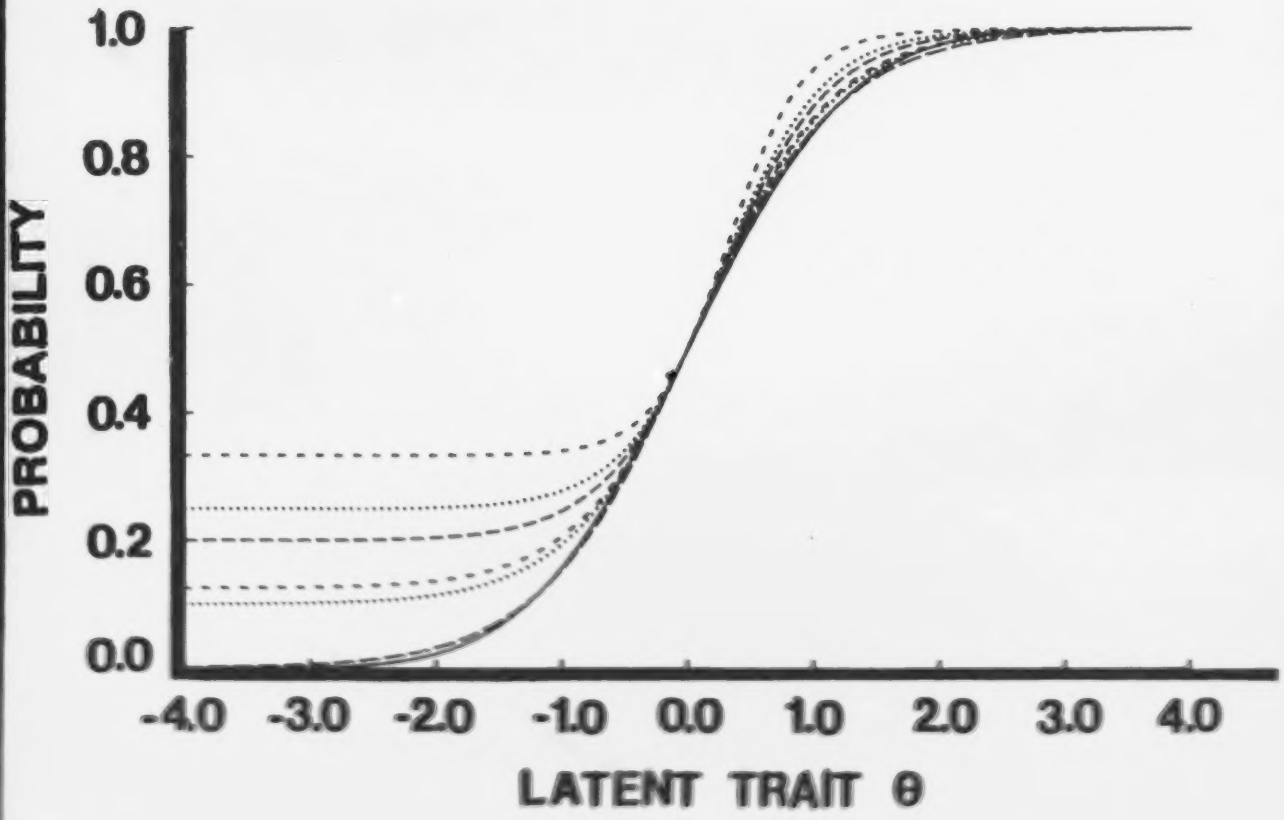

FIGURE 7-14

Item Characteristic Functions in the Three-Parameter Logistic Model with Varieties of Different Values of Guessing Parameter c_g, Approximating the Ones in the Normal Ogive Model (Solid Line) And in the Logistic Model (Longest Dashed Line) with the Two Common Item Parameters, $a_g = 1.00$ And $b_g = 0.00$, And the Scaling Factor, $D = 1.7$, for the Latter. The Values of c_g Are 1/10, 1/8, 1/5, 1/4 and 1/3. Results Obtained by Using the Second Fitting Method.

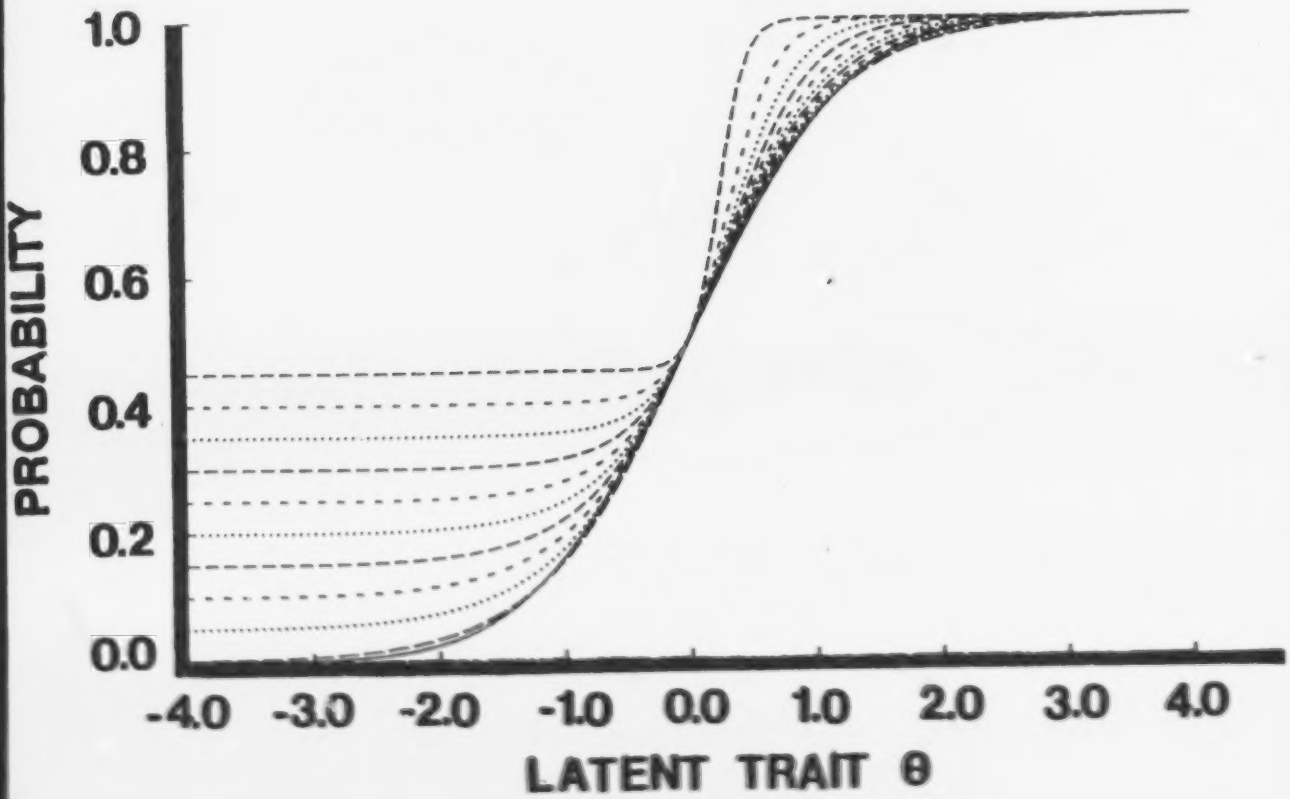

FIGURE 7-15

Item Characteristic Functions in the Three-Parameter Logistic Model with Varieties of Different Values of Guessing Parameter c_g, Approximating the Ones in the Normal Ogive Model (Solid Line) And in the Logistic Model (Longest Dashed Line) with the Two Common Item Parameters, $a_g = 1.00$ And $b_g = 0.00$, And the Scaling Factor, $D = 1.7$, for the Latter. The Values of c_g Are 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45 And 0.50. Results Obtained by Using the Second Fitting Method.

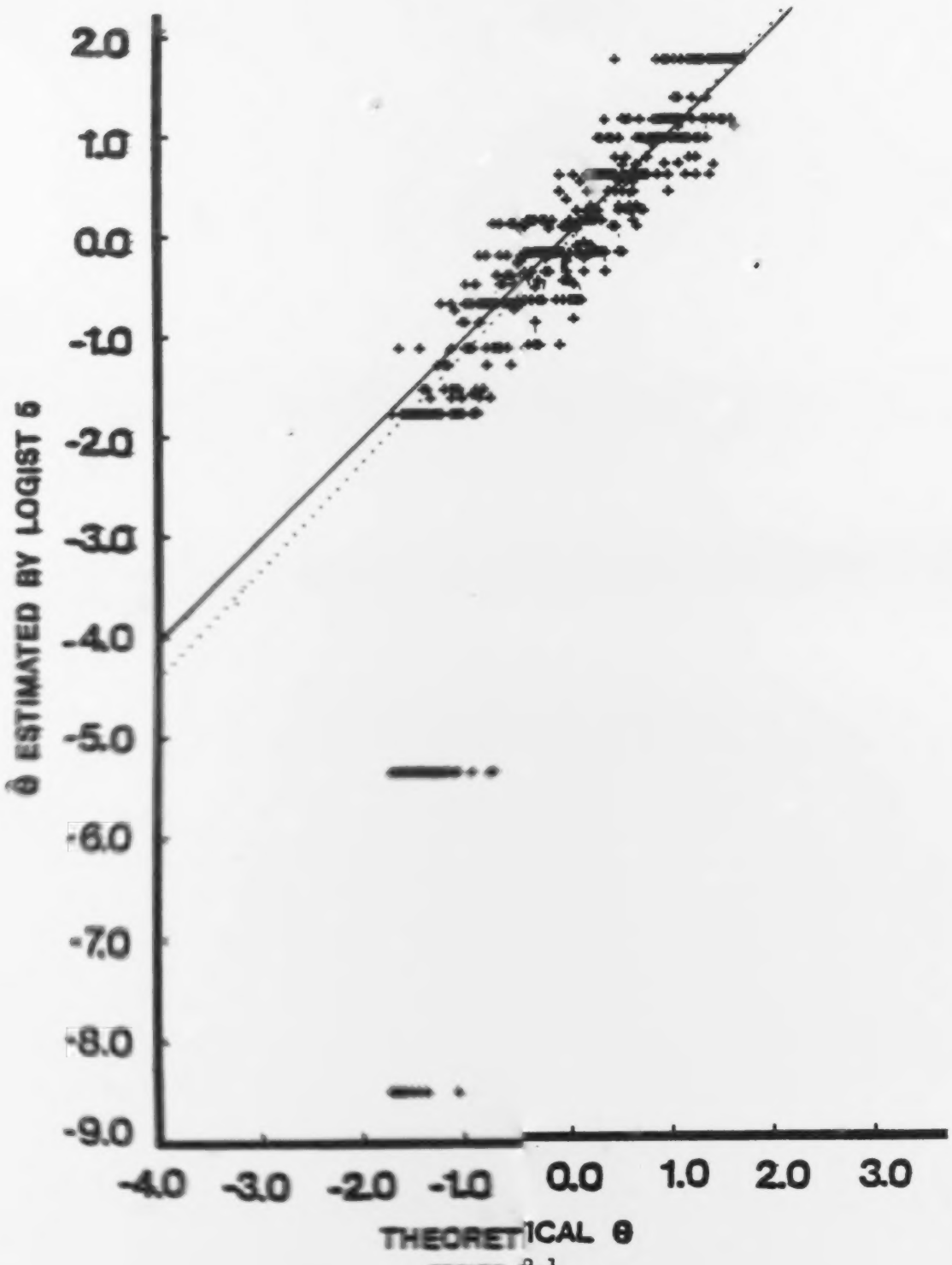

FIGURE 8-1

Estimated Individual Parameters Plotted against the Theoretical Individual Parameters. Three-Parameter Logistic Model Is Assumed. Case 1, 500 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

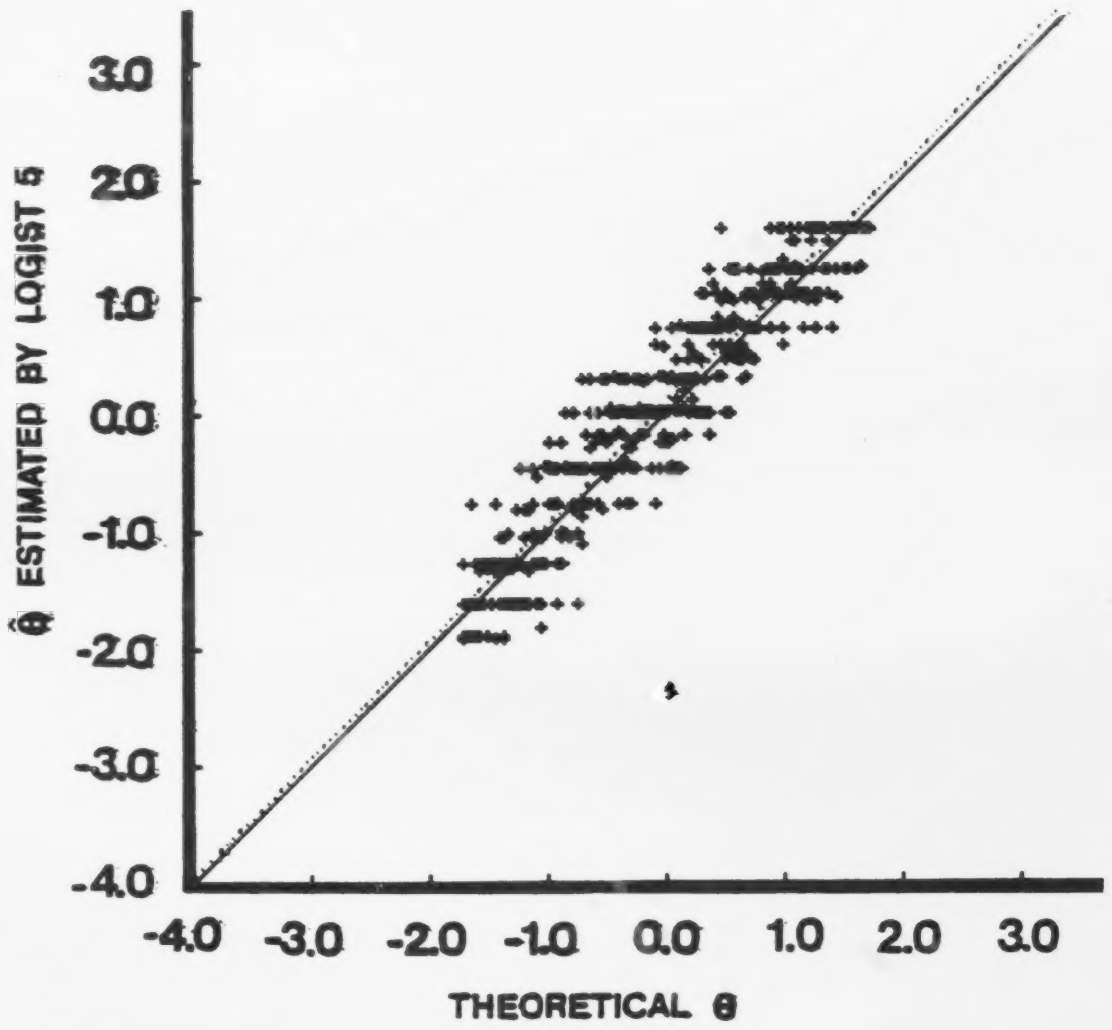

FIGURE 8-1 (Continued): Logistic Model Is Assumed.
Case 1, 500 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

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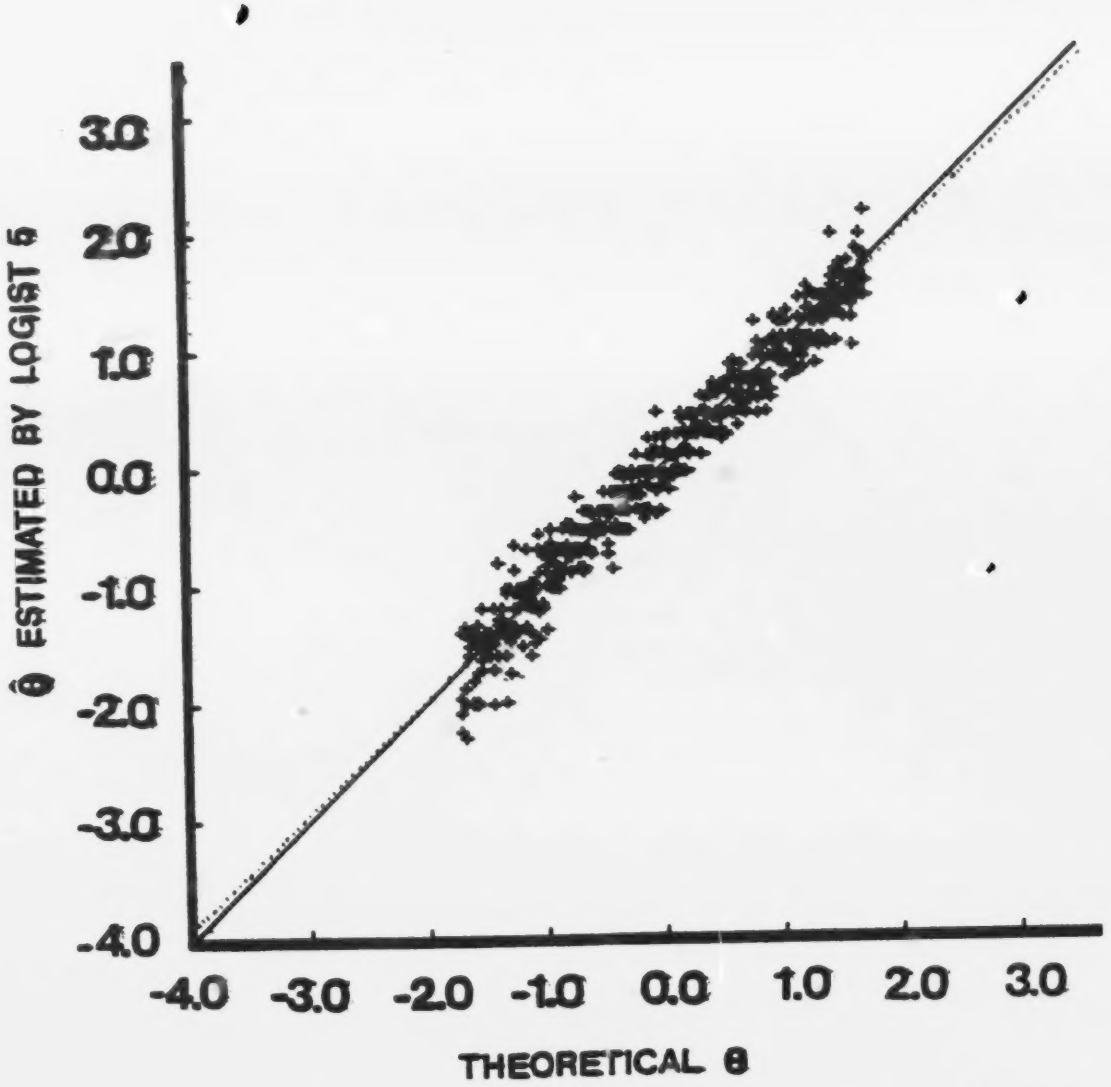

FIGURE 8-2

Estimated Individual Parameters Plotted against the Theoretical Individual Parameters. Three-Parameter Logistic Model Is Assumed. Case 2, 500 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

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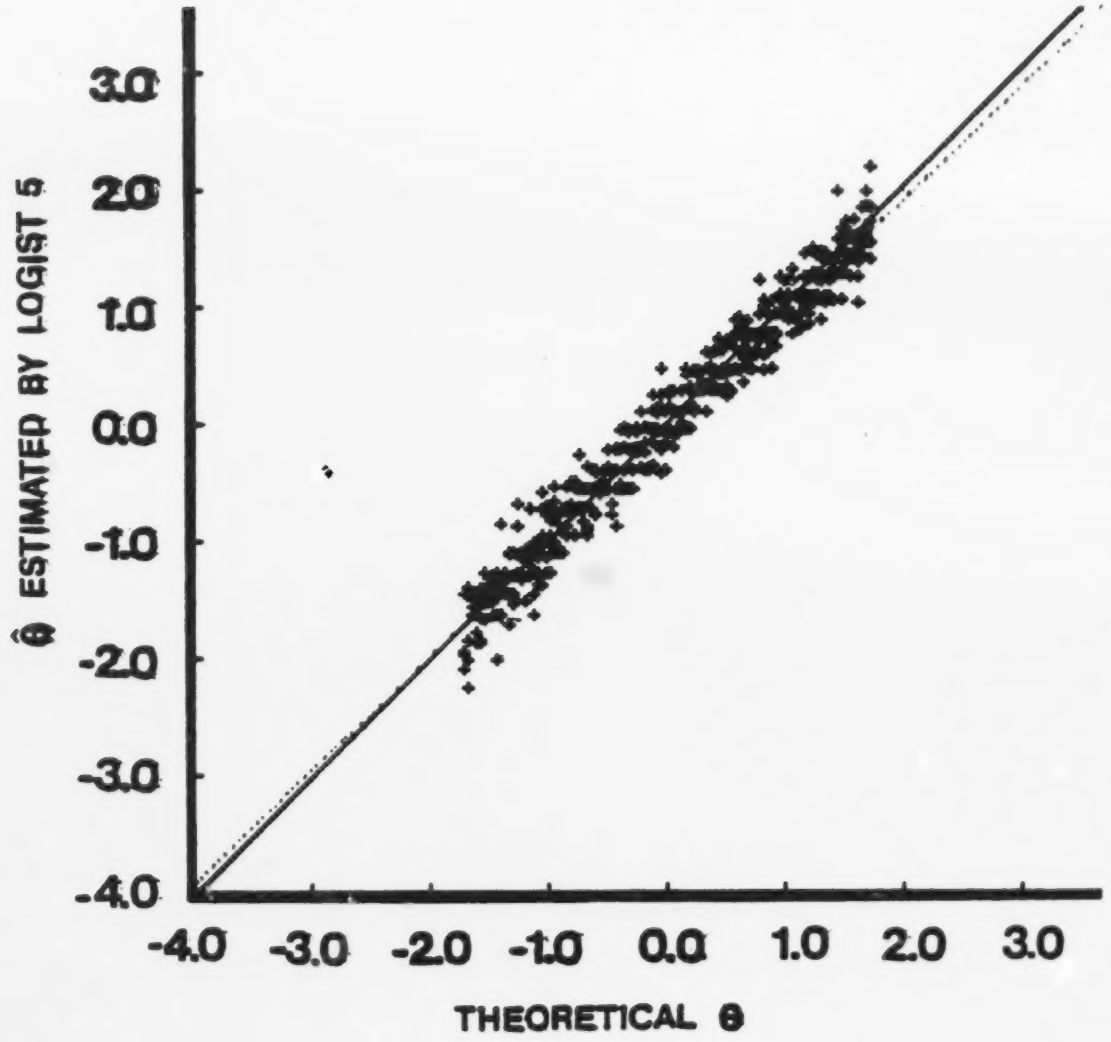

FIGURE 8-2 (Continued): Logistic Model Is Assumed.
Case 2, 500 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

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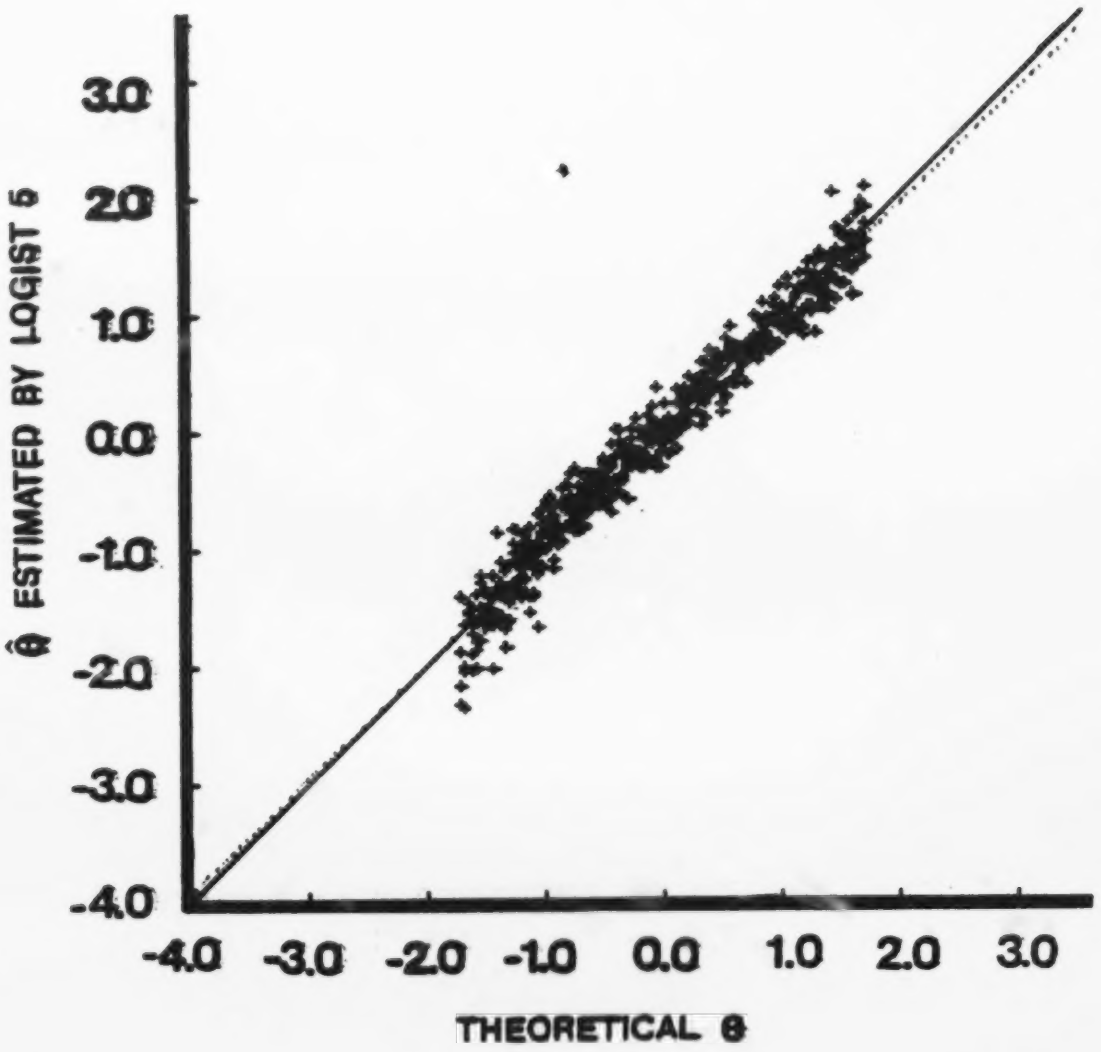

FIGURE 8-3

Estimated Individual Parameters Plotted against the Theoretical Individual Parameters. Three-Parameter Logistic Model Is Assumed. Case 3, 500 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

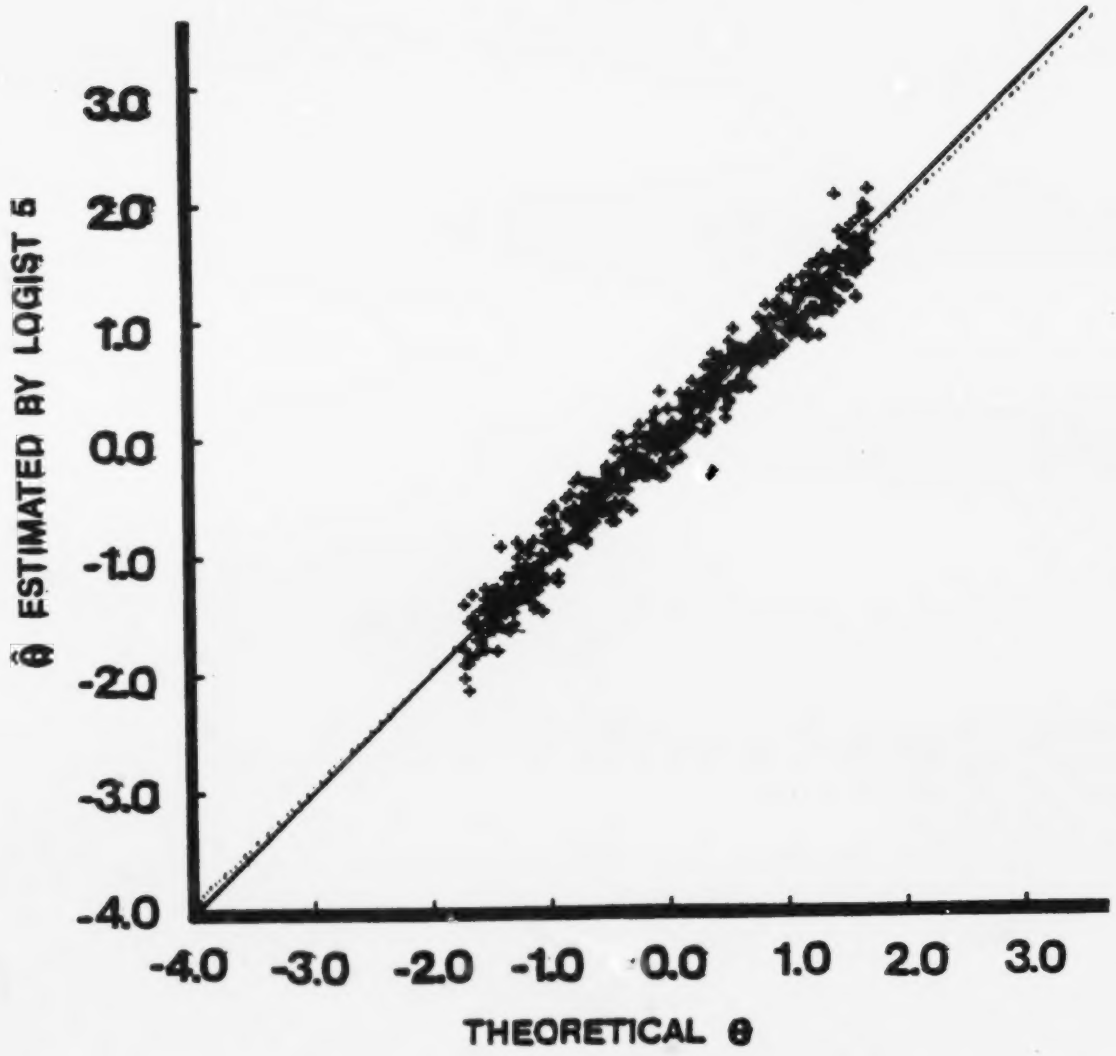

FIGURE 8-3 (Continued): Logistic Model Is Assumed.
Case 3, 500 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

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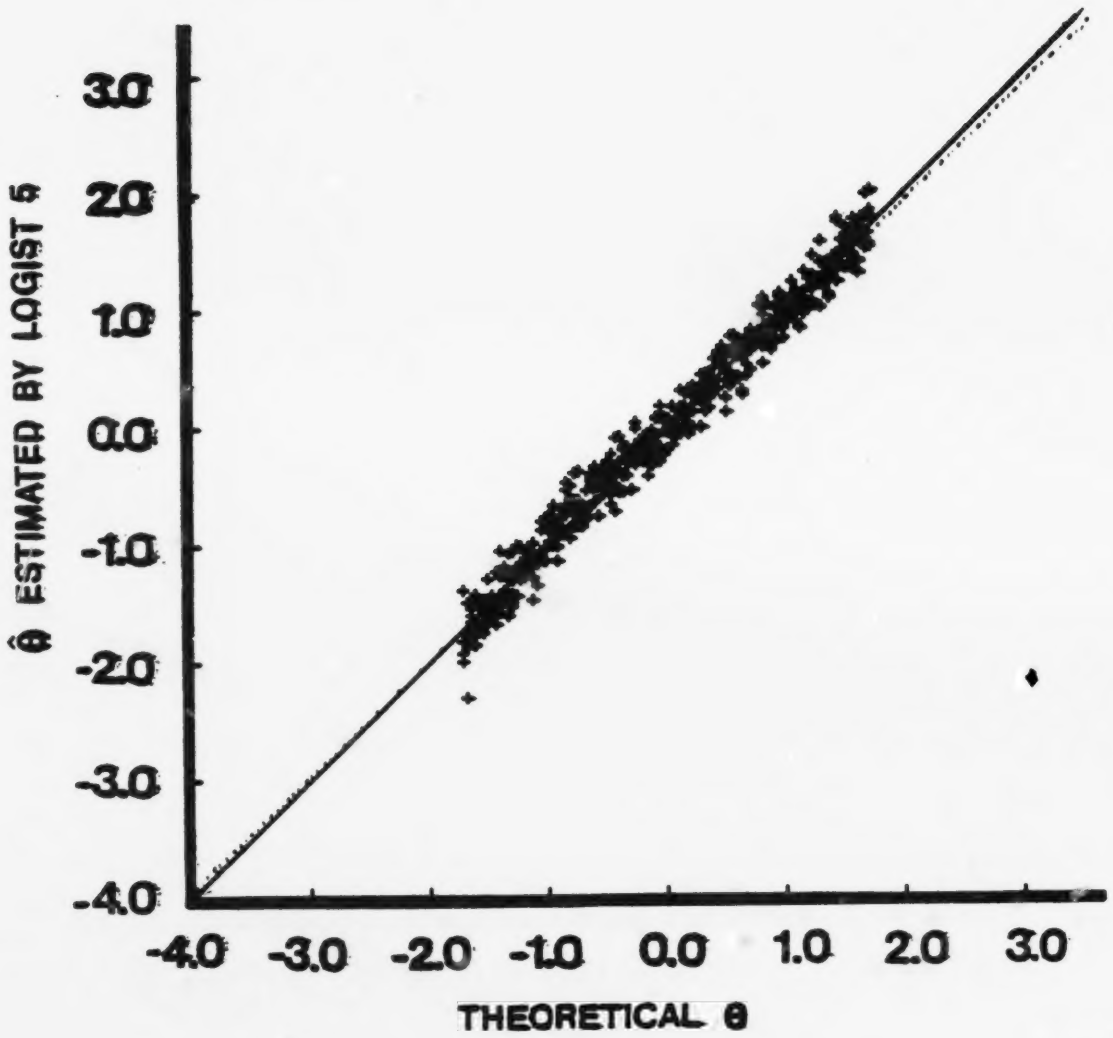

FIGURE 8-4

Estimated Individual Parameters Plotted against the Theoretical Individual Parameters. Three-Parameter Logistic Model Is Assumed. Case 4, 500 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

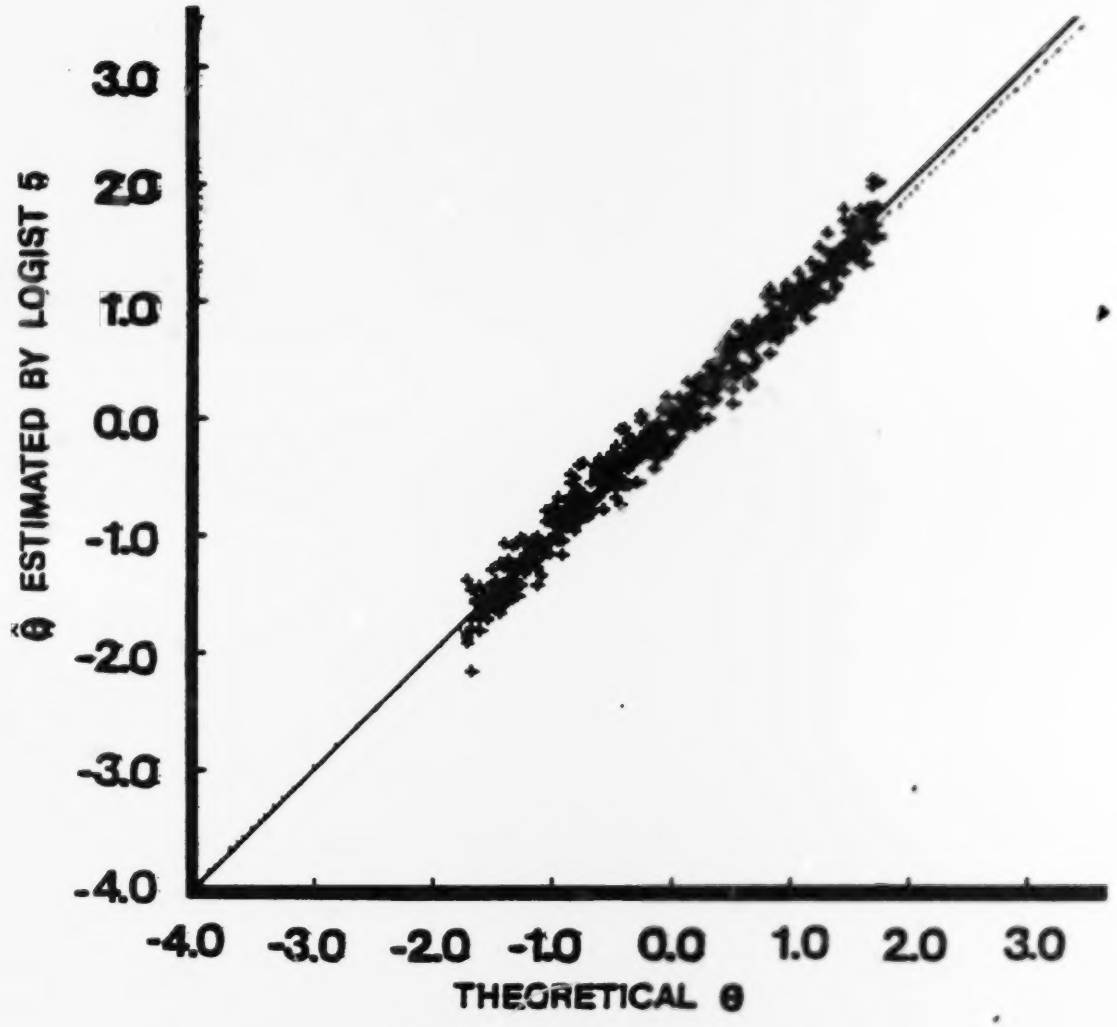

FIGURE 8-4 (Continued): Logistic Model Is Assumed.
Case 4, 500 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

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Cases 1, 2, 3 and 4, respectively, for the 500 Subject Case. Each of these figures has two graphs, i.e., one for the results obtained by assuming the three-parameter logistic model and the other for those obtained by assuming the (two-parameter) logistic model. In Figure 8-1, or in Case 1, those hypothetical examinees having either the all zero response pattern or the all unity response pattern were excluded, since their ability estimates are either negative or positive infinity and cannot be plotted. In each graph, a solid line diverging the abscissa with the angle of 45 degrees and passing (0,0) is drawn, indicating the asymptotic unbiasedness of estimation. In addition to this line, the sample linear regression of the estimated individual parameter on the true ability, or the best fitted line based upon the least squares principle, is also presented by dots. It is recalled that in the result of Logist 5 the scale of θ is adjusted in such a way that the sample mean of the estimated individual parameters is set equal to the origin, and the sample standard deviation is used as the unit. This was done including all the 500 hypothetical examinees in Cases 2, 3 and 4, respectively. A substantial number of examinees were excluded in each of the two situations of Case 1, however, in the process of this standardization of θ because of their extremely deviated values of ability estimates. When the logistic model is assumed, those deviated ability estimates are either negative or positive infinity caused by the all zero or the all unity response pattern. When the three-parameter logistic model is assumed, however, those individuals clustered at the lower left of the first graph of

Figure 8-1 were also excluded in addition to those obtaining either negative or positive infinity as their ability estimate. In obtaining the linear regression in Case 1, this same subset of examinees included in the rescaling of θ was solely used in each situation. They number 400 when the three-parameter logistic model is assumed, and 453 when the logistic model is assumed. The correlation coefficients between the estimated and true individual parameters for those subsets of examinees turned out to be approximately 0.9249 and 0.9425 in those two situations, respectively, and the mean and the standard deviation of the true individual parameters are approximately 0.0709 and 0.8511 in the former and -0.0985 and 0.9295 in the latter. Thus in Case 1 the sample linear regression of the estimated individual parameter on the true individual parameter is approximately $1.0853\theta - 0.0769$ when the three-parameter logistic model is assumed, and $1.0129\theta + 0.0998$ when the logistic model is assumed. In Cases 2, 3 and 4, since both Logist 5 scale and the true θ scale are standardized with respect to the same ability distribution, the sample linear regression equals the true ability θ multiplied by the sample correlation coefficient between the estimated and the true individual parameters. These correlation coefficients turned out to be 0.9790 and 0.9812 in Case 2, 0.9814 and 0.9849 in Case 3, and 0.9892 and 0.9898 in Case 4, respectively, in the two separate situations in each case. We can see in Figures 8-1 through 8-4 that, except for the first situation in Case 1, the linear regressions which are shown by dots in these graphs, are very close to the corresponding solid lines,

which diverge the abscissa with the angle of 45 degrees and passing (0,0). This implies that, if we use a linear transformation as an approximation to the transformation of the ability scale obtained as the result of Logist 5 in Cases 2, 3 and 4, the reduction in the unit will be, at most, 2 percent, in view of the asymptotic conditional unbiasedness of the maximum likelihood estimate. These results justify the direct comparison of the estimated item parameters with the theoretical ones in Cases 2, 3 and 4, which was made in the preceding three sections. They also explain, partly, some disastrous results of the item parameter estimation in Case 1, which were observed in those previous sections.

The corresponding results for the 2,000 Subject Case are presented as Figures 8-5 through 8-8. Again in Case 1 a substantial number of examinees were excluded in the process of rescaling θ, and they were also excluded in obtaining the linear regression of the ability estimate on the true ability in each of the two situations. Those who were included number 1,762 when the three-parameter logistic model is assumed and 1,815 when the logistic model is assumed. The two correlation coefficients between the estimated individual parameters and the true individual parameters in the two situations are 0.9155 and 0.9447, respectively, and the linear regression is given by $1.0020\theta + 0.0441$ in the former situation and $1.0128\theta + 0.0869$ in the latter. In Cases 2, 3 and 4, those pairs of correlation coefficients are 0.9801 and 0.9809, 0.9843 and 0.9854, and 0.9904 and 0.9907, respectively, and they are also

the coefficients of the linear regressions which have uniformly zero as their intercepts in the six separate situations. Again, except for the first situation of Case 1, these linear regressions are almost indistinguishable from the line diverging the abscissa with the angle of 45 degrees and passing (0,0). As was expected, these results are very similar to those obtained in the 500 Subject Case.

IX. *Discussion and Conclusions*

Three-parameter logistic model was assumed for the item characteristic functions of the hypothetical test items upon which data were simulated, although they actually follow the normal ogive model, and Logist 5 was used upon simulated data for estimating the three item parameters of each item as well as the individual parameters. In so doing, four different cases, each of which has a different number of test items, and two hypothetical subject groups of different numbers of individuals were adopted. For the sake of comparison, the whole procedure was repeated by assuming the (two-parameter) logistic model by setting $c_g = 0.0$ in using Logist 5.

It was discovered that the estimated discrimination parameters thus obtained were generally inflated, even if they were adjusted by the discrimination shrinkage factor, which is proposed in the present paper. This inflation of the estimated discrimination parameters obtained by Logist 5 was also observed when there should be no inflation, i.e., when the logistic model was assumed. It was also discovered that the estimated difficulty parameters were also

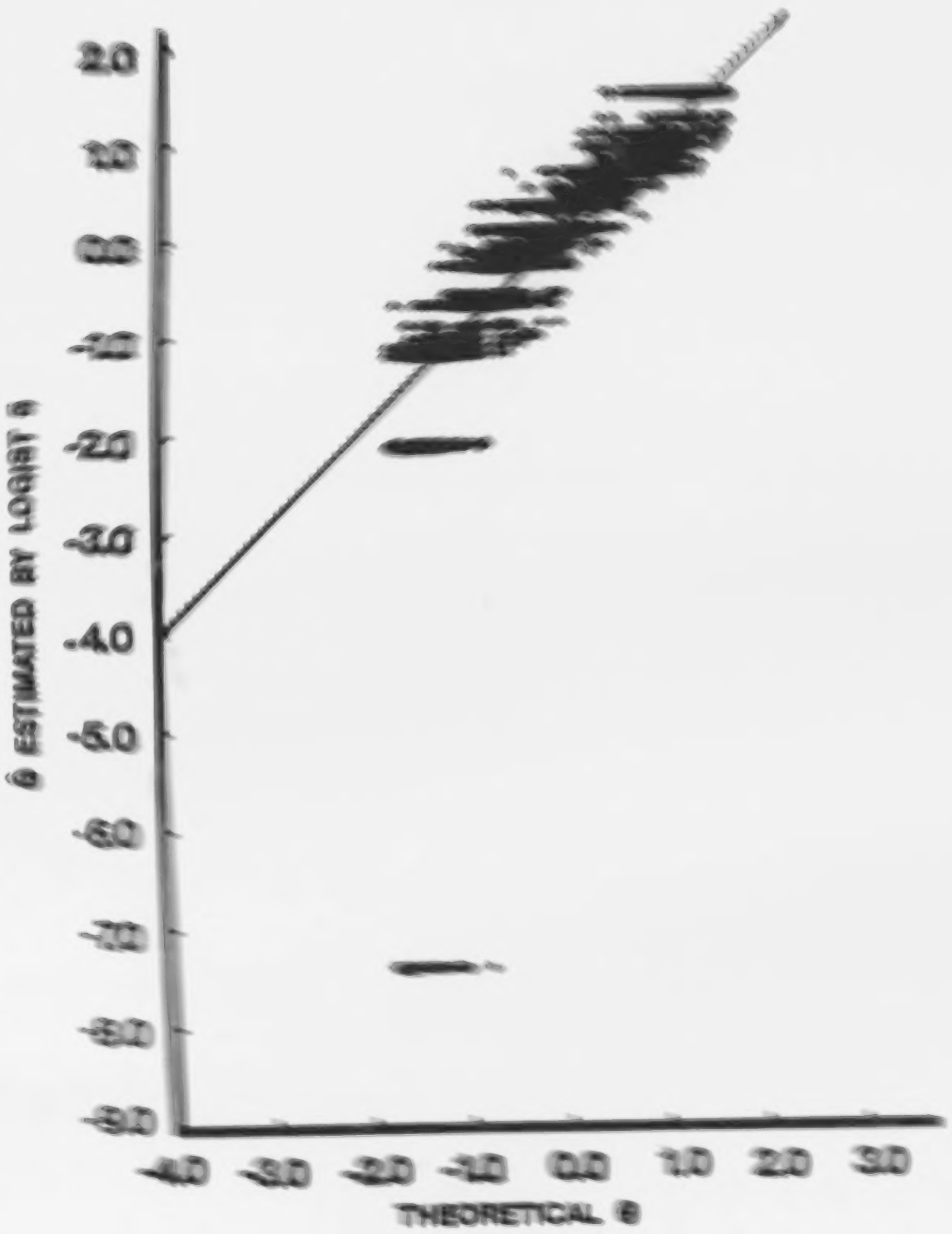

FIGURE 8-5

Estimated Individual Parameters Plotted against the Theoretical Individual Parameters. Three-Parameter Logistic Model Is Assumed. Case 1, 2,000 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

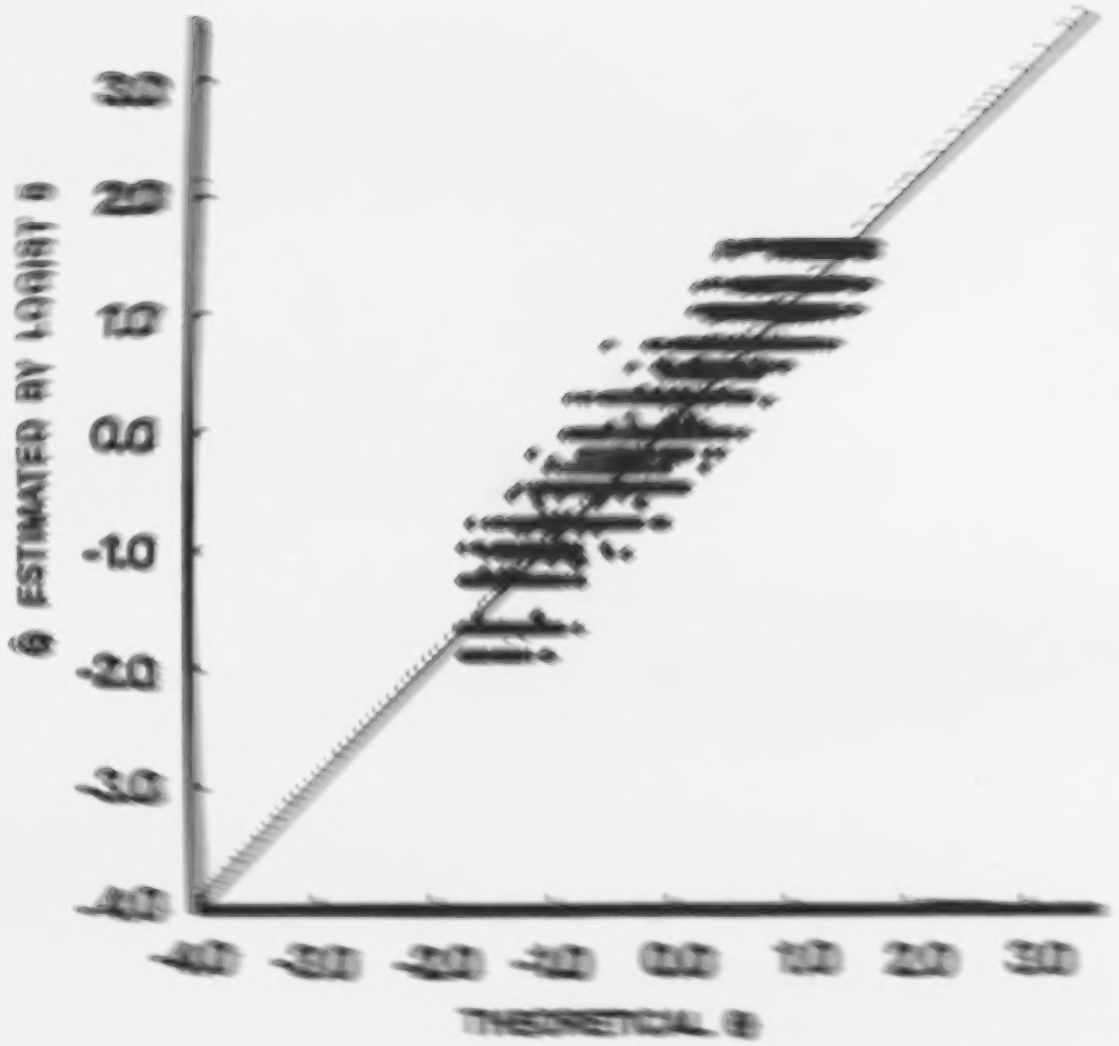

FIGURE 6-5 (Continued): Logistic Model Is Assumed.
Case 1, 2,000 Subject Case.

(Linear Regression of θ̂ on θ Is Plotted by a Dotted Line.)

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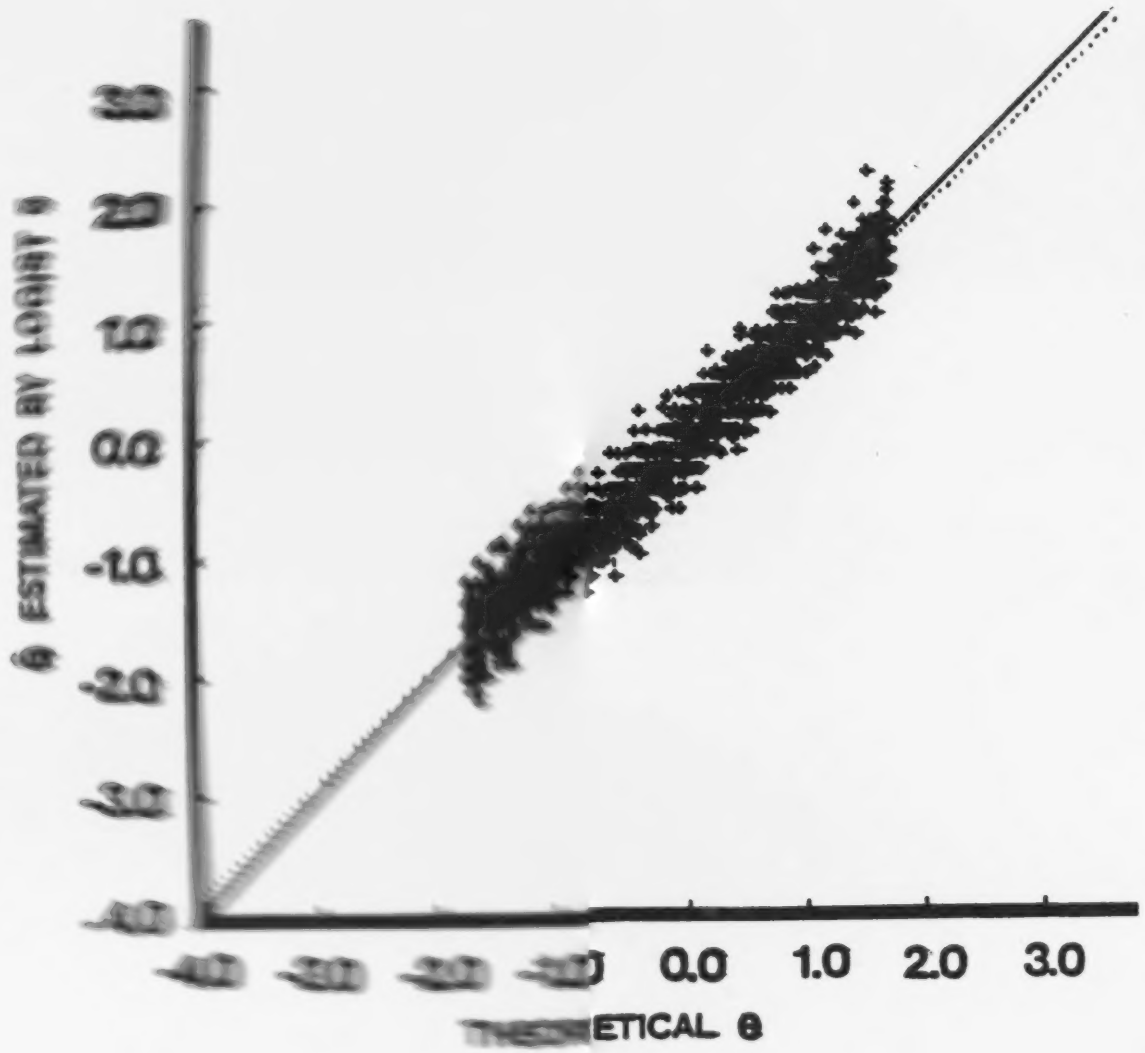

E 8-6

Plotted against the Theoretical
e-Parameter Logistic Model Is
,000 Subject Case.

Is Plotted by a Dotted Line.)

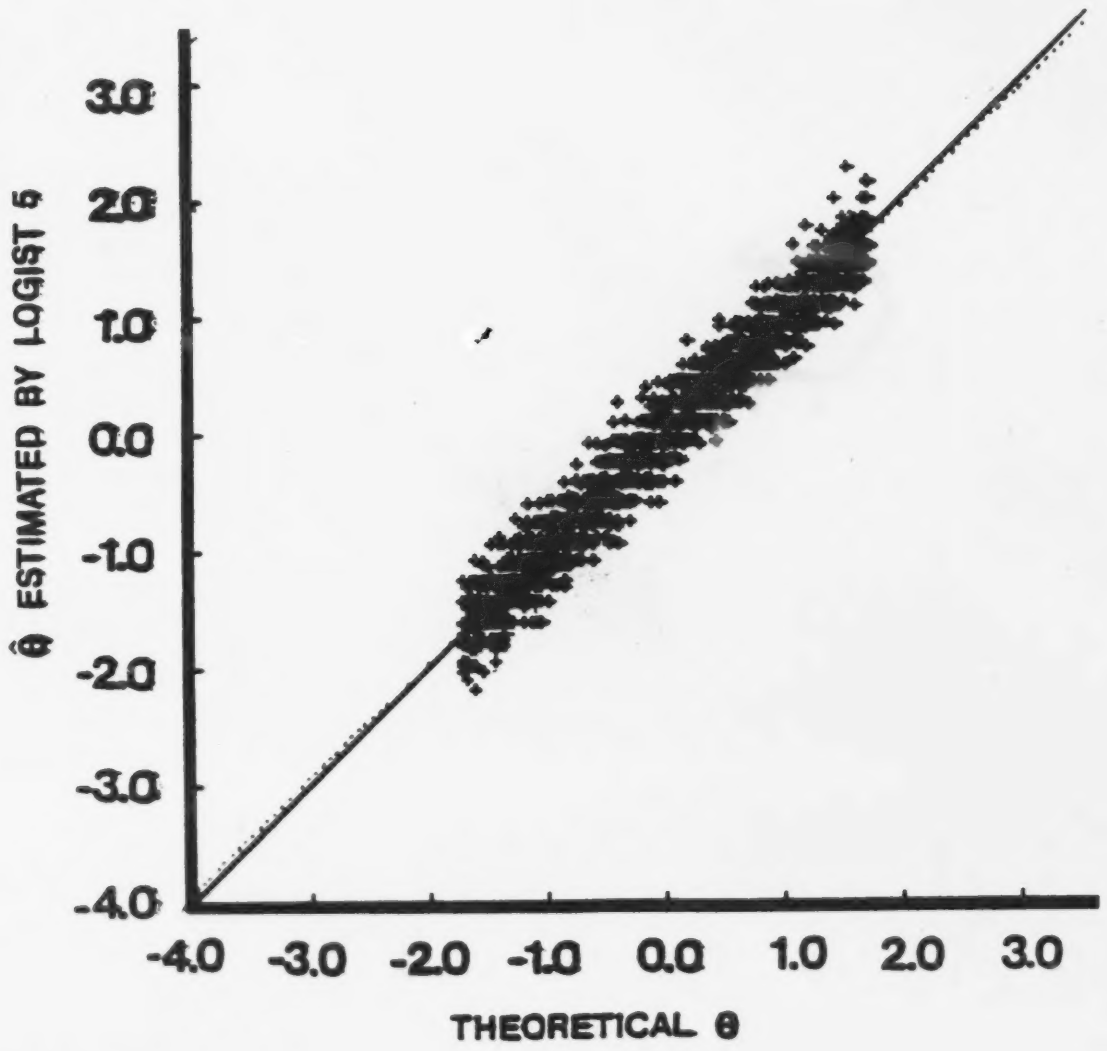

FIGURE 8-6 (Continued): Logistic Model Is Assumed.
Case 2, 2,000 Subject Case.
(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

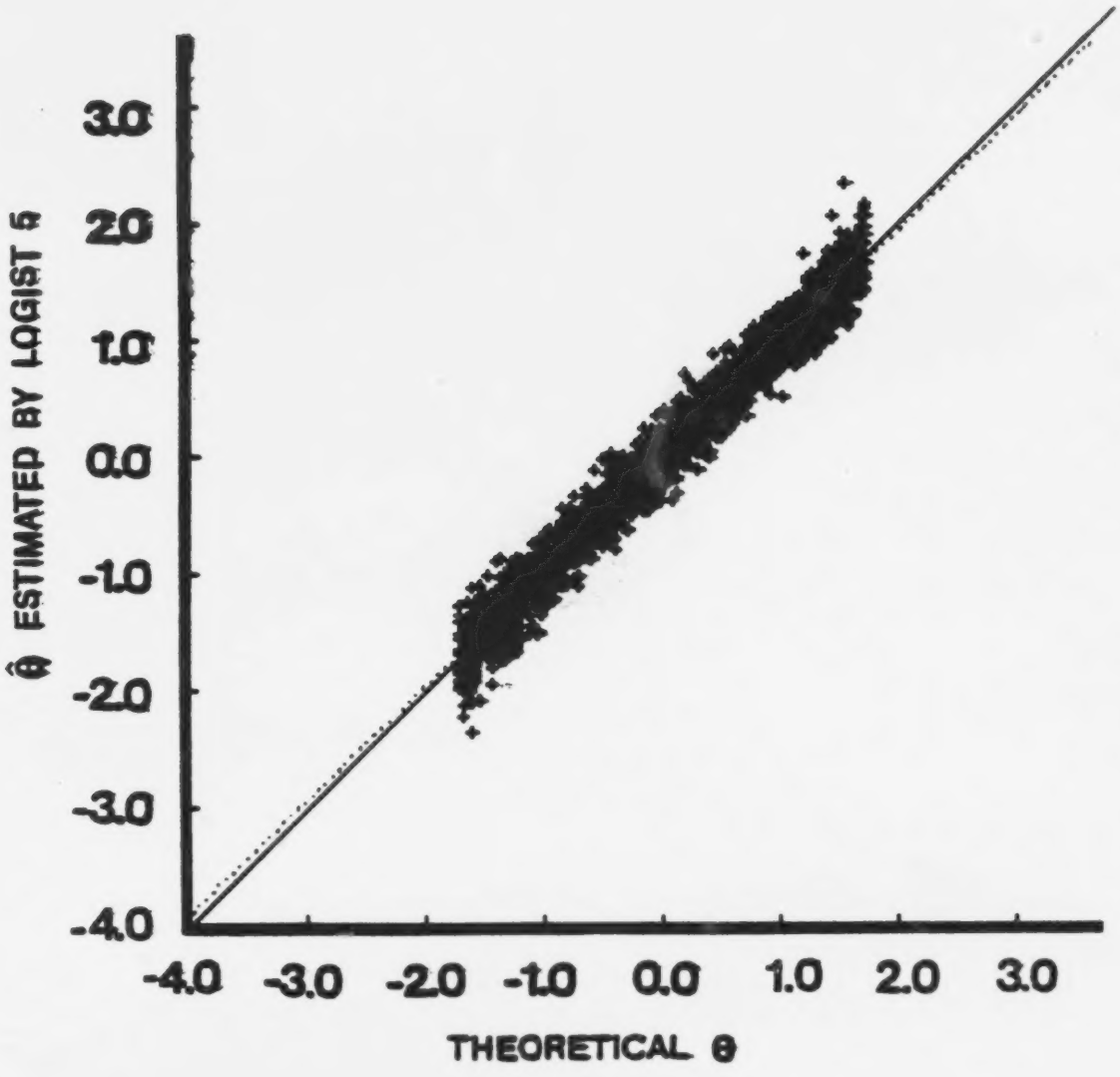

FIGURE 8-7

Estimated Individual Parameters Plotted against the Theoretical Individual Parameters. Three-Parameter Logistic Model Is Assumed. Case 3, 2,000 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

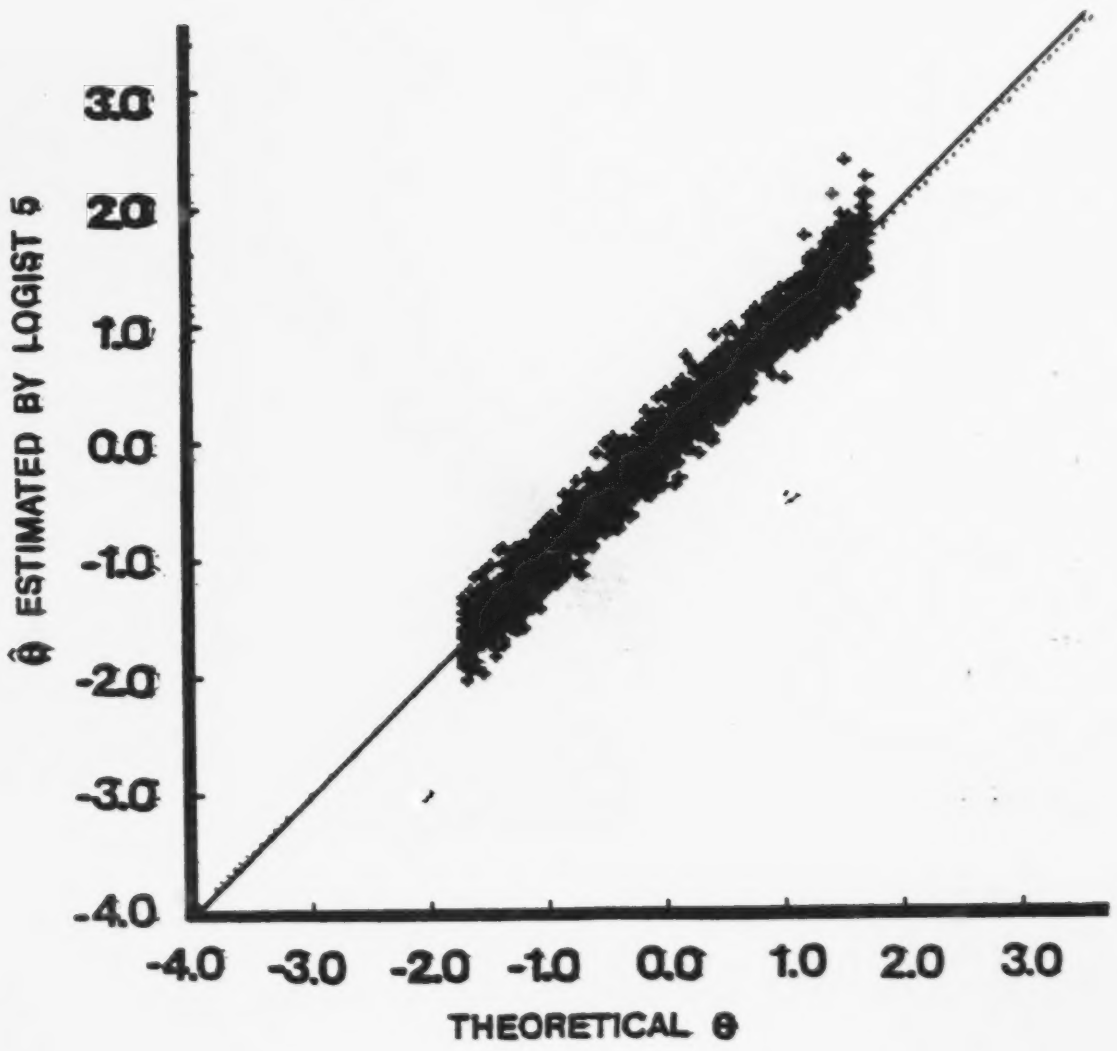

FIGURE 8-7 (Continued): Logistic Model Is Assumed.
Case 3, 2,000 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

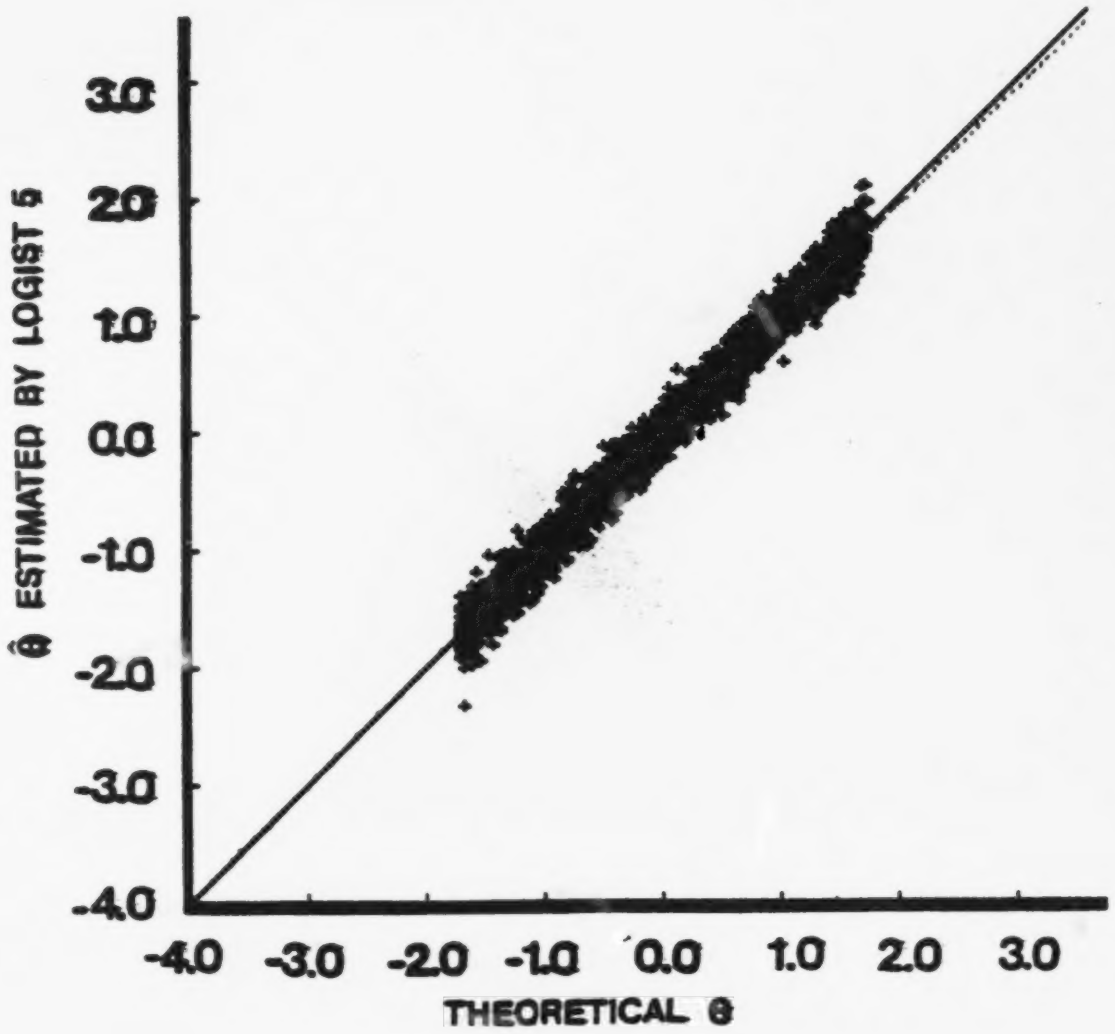

FIGURE 8-8

Estimated Individual Parameters Plotted against the Theoretical Individual Parameters. Three-Parameter Logistic Model Is Assumed. Case 4, 2,000 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

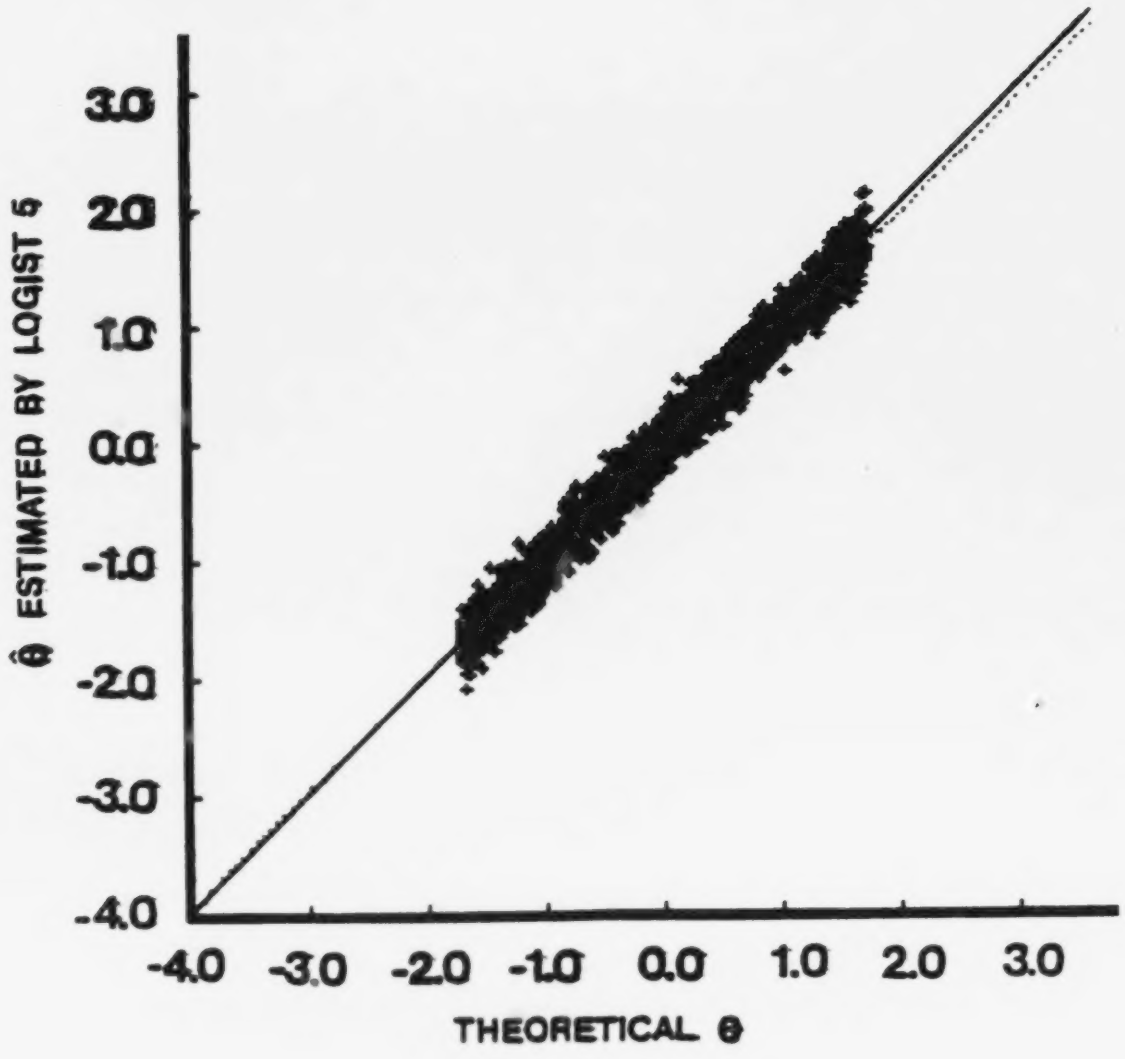

FIGURE 8-8 (Continued): Logistic Model Is Assumed.
Case 4, 2,000 Subject Case.

(Linear Regression of $\hat{\theta}$ on θ Is Plotted by a Dotted Line.)

enhanced, but not to the extent the estimated discrimination parameters were. The difficulty reduction index, which was also proposed in the present paper, eliminated those discrepancies well.

Some resulting estimated item characteristic functions are disastrously different from the theoretical item characteristic functions, especially in Case 1 where only ten binary test items were included. This seems largely due to the fact that in Logist 5, in estimating the item parameters, the estimated individual parameter, which is based upon the maximum likelihood estimation, is treated as if it were the true individual parameter, and its large error of ability estimation caused by the small number of items affects the item parameter estimation, especially near the endpoints of the interval of θ for which our subjects' ability distributes. Thus the estimated item characteristic functions of very easy test items become disastrously different from the true item characteristic functions. Since there is no functional relationship between θ and its maximum likelihood estimate $\hat{\theta}$, there is no simple way to correct these biases. We must keep in mind that in using Logist 5, or any other program based upon the same principle, the number of test items must be substantially large, and the items whose parameters are to be estimated must be of intermediate difficulty relative to the ability distribution. It appears that forty-five is not a large enough number of items to be included, and that we need at least some number in the vicinity of eighty, in order to make a good use of Logist 5. Otherwise, we will obtain false "tails" caused by large values of the

estimated guessing parameters, which are supposed to be zero. The fact that the estimated discrimination parameters tend to be inflated, even when we set the guessing parameter equal to zero, appears to be still mystifying. If we consider the problem in scale adjustment discussed in Section 3, however, we notice that these results imply some important information. Since in the results of Logist 5 the mean and the standard deviation of the maximum likelihood estimate of ability, instead of those of ability themselves, are used as the origin and the unit of θ, respectively, those inflated estimates of a_g indicate that the standard deviation of the maximum likelihood estimate may actually be larger than that of ability, in each of the sixteen different situations. This will be observed further and discussed later in a separate paper.

We find no substantial differences between the results of 500 Subject Case and 2,000 Subject Case. This indicates that increasing the number of subjects from 500 to 2,000 does not provide us with a substantial gain.

The results of the present research imply the warning that it is dangerous to assume three-parameter logistic model when we have no evidence for its validity, especially when the items are relatively easy in comparison with the ability distribution. It may provide us with large "tails" in the estimated item characteristic functions, when actually they do not exist.

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[7] Wingersky, M. S., M. A. Barton, and F. M. Lord. Logist User's Guide. Princeton: Educational Testing Service, 1982.

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